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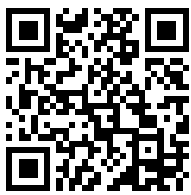

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OF THE

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THE EFFECT OF HIGH TEMPERATURE, HUMIDITY, AND WIND ON THE HUMAN BODY.

BY C. W. B. NORMAND, M.A., B.Sc., F.R.Met.Soc., Meteorological Office, Simla

[Received October 11—Read November 19, 1919.]

1. INTRODUCTION: THE SIMOOM.

WHILE in Mesopotamia I heard of a Political Officer who, when travelling in the neighbourhood of Dizful during an exceedingly hot spell in July 1917, had found some Persians lying dead in the desert. To him the deaths appeared to be due not to thirst but to the suffocating effects of the strong, hot, and exceedingly dry wind. This recalled stories of the fatal effects of the simoom and made one wonder about the cause of such deaths. For though speculations on this point may properly be the privilege of the physiologist, the meteorologist may be expected to be able to define atmospheric conditions which must be fatal —to be able to state, for example, the conditions of humidity, temperature, and air movement that are necessary and sufficient to prevent the healthiest of human bodies from cooling rapidly enough by evaporation to counteract the rate of heating by convection.

People fight shy of hot desert plains. Consequently little that is definite has been written about fatal simoom effects. I know of no recent writings on the simoom, but there seem to have been in the past at least two schools of ideas on the subject. On the one hand there is the more generally accepted definition of simoom as a hot dry wind of high velocity, the fatal effects of which are ascribed to its heat and dryness. Ferrel[1] says, "The simoom stripped of all exaggeration is probably one of these dust whirlwinds." The other view has been expressed by Blanford in his *Vade Mecum*. He says that "some facts collected by Dr. H. Cook on cases of the simoom in upper Sind and Cutchee certainly seem to sanction the inference that something more than mere heat and dryness have acquired for this scourge of the desert its ominous name of

[1] *Report of Chief Signal Officer*, Washington, 1885, pt. ii. p. 331.

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the 'Poison wind,'" though "unfortunately the evidence is at present too meagre to admit of any decided opinion."[1]

The latter view need not be considered further as the evidence is still insufficient to determine how far Blanford was right. But whether or not there are cases which demand something more than a purely physical explanation, we can conceive the occasional occurrence of atmospheric conditions under which, from purely physical causes, human life would be impossible, and can attempt at least an approximate definition of such conditions.

It is impossible to resist the conclusion that the velocity of the wind rather than its temperature is the essential feature in those cases of simoom which are to be explained from physical causes only. For, over tropical and subtropical deserts in the heat of summer, the calm days are those which offer the most favourable conditions for high air temperatures near the ground. The fall of temperature with height just above the surface is then very rapid. On the other hand, a high wind, by increasing turbulence, produces a less rapid vertical temperature gradient and generally a lower air temperature near the surface. Even the onset of a whirlwind or tornado on an otherwise calm day cannot be expected to raise the surface air temperature, but rather gradually to decrease it. These facts have to be reconciled with the essential property of the simoom, namely, a suffocating wind like the blast of a furnace, and presumably therefore a wind feeling hotter than the air did before the simoom's onset. Remembering that the feeling of heat or cold is a question of the rate of loss of heat in the human body, we can explain a feeling of greater heat in spite of no actual increase in the air temperature if it is true that at high temperatures the body rate of heat loss is greater in a calm or light wind than in a high wind, and especially if it is true that a high wind may result in a net gain of heat to the body. For it is a reasonable assumption, which we shall make throughout this paper, that atmospheric conditions resulting in a net gain of heat to the body must be fatal.

2. A Physiological Point of View.

From the physiological point of view it is reasonable that the effect of wind should be as described above, since there is a maximum rate at which the healthiest sweat glands can secrete sweat. In reply to a query of mine about the maximum rate of perspiration, Capt. R. C. T. Evans, R.A.M.C., described this point from the medical man's point of view as follows:

"Suppose a man standing bare in a desert but shaded from the actual rays of the sun. There is no wind at first. He will feel hot and will, if healthy, perspire. The particles of water vapour escape only by diffusion from him so that the cooling is slow. He physiologically reacts by pouring out more sweat; this is one reason why 'visible' perspiration is so much more pronounced in still air. Not only is less evaporated, but more is secreted in a blind physiological attempt to get greater cooling. Now suppose the man perspiring correctly for still air and with sweat standing on him, and suppose the air now moves in a gentle current, the temperature and humidity being the same as

[1] *Indian Meteorologists' Vade Mecum*, *Calcutta*, 1877, pt. ii. pp. 133–134.

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before. The sheath of saturated air round his body is removed, the skin loses heat at a greater rate, temperature falls, and the body begins to perspire less in order to regain equilibrium, or rather a comfortable temperature. As the velocity of the wind slowly increases the clearing away of the sheath of water vapour fairly soon reaches a practical maximum and the temperature of the wind begins to count. The body responds by pouring out more moisture till again comfort is reached. Any sudden puff above what is required to carry off the steady flow of vaporised sweat at any stage of equilibrium, feels hot, and if the increased wind velocity is maintained the body has to respond with more sweat. At last a point is reached where physiologically the skin cells are doing their utmost. This point from the body's point of view depends on the health, the constitution of the blood at the time, and the resources of moisture in the tissues. Any speed of wind above this would feel hot, and as the evaporation is working at its maximum—no greater rate of sweating being possible—the body would be heated up."

Because, therefore, the bodily gain of heat by convection from the air increases as the strength of the wind increases and because the human body cannot perspire above a certain maximum rate, it is easy to see that to each air temperature above blood heat there must, theoretically at least, correspond a certain critical value of the wind velocity, which, if exceeded, must produce a net gain of heat to the body. Also the lower the air temperature the higher will be the critical wind velocity at which conditions become unlivable. Under actual atmospheric conditions this limit appears never to be exceeded except in an exceptionally hot and high wind. It may, too, be emphasised that the simultaneous occurrence of great heat and high wind is most likely in actions akin to tornado action on an otherwise calm day, when the very hot surface air is suddenly set in motion.

3. Gain and Loss of Heat by the Human Body.

The above is only a qualitative analysis of the problem. As a first step in the quantitative analysis the profit and loss account of heat in the human body may be written thus:

Gain of Heat by	Loss of Heat by
(*a*) Air convection.	(*d*) Evaporation from skin.
(*b*) Sun's or other radiation.	(*e*) Evaporation from respiratory membrane.
(*c*) Body production of heat.	

(*c*) and (*d*) are physiologically controlled. (*a*), (*b*), and (*e*) are dependent upon atmospheric conditions. Under ordinary climatic conditions the body functions as an automatically regulated thermostat, in which the net loss and the net gain of heat are maintained equal to one another. But when the upper limit of existence is reached the body must reduce (*c*) to a minimum and increase (*d*) to a maximum, so that the whole skin will tend to act as a wet surface. We may therefore look to physical experiments on the rate of cooling of wet surfaces at body temperature under varying atmospheric conditions to supply the data for determining the upper limits for existence.

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4. Application of Katathermometer Formula to estimate Upper Climatic Limit.

At first it was thought that these conditions would be obtained directly from the work on the wet katathermometer, the instrument which Prof. Leonard Hill has introduced to estimate the cooling powers of the atmosphere. The relationship between the wet-kata readings and the temperature, humidity, and movement of the air has been considered by Prof. Leonard Hill and collaborators in two papers.[1] The formulae deduced from numerous experiments are :

For the dry-kata

$$H = (0{\cdot}27 + 0{\cdot}49\sqrt{V})(T - t). \quad . \quad . \quad . \quad (1)$$

For the wet-kata

$$H' = (0{\cdot}27 + 0{\cdot}49\sqrt{V})(T - t) + (0{\cdot}085 + 0{\cdot}102V^{0.3})(F - f)^{\frac{1}{3}}, \quad (2)$$

where H, H′ are the heat losses from dry and wet katas respectively in milli-cals./cm.^{2}/sec., V the wind velocity in m.p.s., T the kata temperature (36°·5 C.), t the air temperature (° C.), F the saturation vapour pressure at 36°·5 C. (45·4 mm.), and f is the vapour pressure of the air. It must be emphasised that these are purely empirical formulae based upon experiments with katathermometers.[2]

For our purpose it is better to write equation (2) in the form

$$\left.\begin{aligned} &H' = X + Y\sqrt{V}, \\ \text{where} \quad &X = 0{\cdot}27(T - t) + 0{\cdot}085(F - f)^{\frac{1}{3}} \\ &Y = 0{\cdot}49(T - t) + 0{\cdot}102V^{-0.2}(F - f)^{\frac{1}{3}} \end{aligned}\right\}. \quad . \quad . \quad (3)$$

It is then readily seen that the heat loss, H′, of the wet-kata is zero in a calm, if X = 0, while in an infinite wind H′ can be zero only if $(t - T)$ is an infinitesimally small quantity, *i.e.* if $(t - T) = 0$. The curve of the equation X = 0 is represented in Fig. 1 on a temperature-relative humidity diagram. On the left-hand side of the curve the value of X is positive, along the curve X is zero; and on the other side X is negative. In other words, if the air is calm, a wet katathermometer will cool under conditions of temperature and humidity represented in the X-positive region, but will heat up under the conditions of the X-negative region. In the case of infinite wind

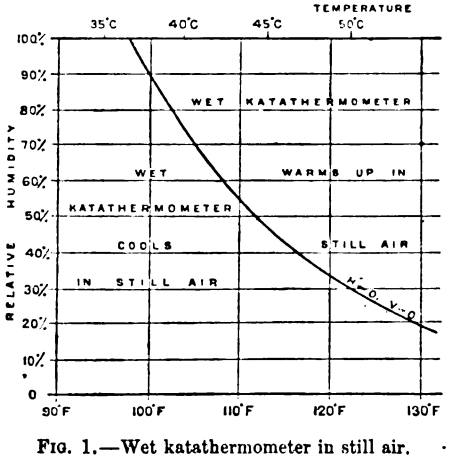

Fig. 1.—Wet katathermometer in still air.

[1] *London, Phil. Trans. R. Soc.*, **207** (ser. B), 1916, p. 183 ; *London, Proc. R. Soc.*, **95** (ser. B), 1919, p. 438.

[2] The katathermometer is a large-bulbed thermometer which may be dry or wet, and which is raised to the temperature of 100° F., and is then exposed. From the time which is required for a fall of 5° F. the rate of cooling may be calculated in milli-calories per cm.^{2} per sec.

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the dividing line between the regions of loss and of gain of heat by a wet-kata is simply the isothermal of $t = T = 36°{\cdot}5$ C. This is represented in Fig. 2. Now by combining Figs. 1 and 2 a diagram (Fig. 3) is obtained which is divided up by the two curves into three regions. In the two outer regions the katathermometer either cools or heats up, no matter what the air movement is. The interesting part is the region between the curves, in which the katathermometer will cool, if the air is still, but will heat up if the air motion is very great. In fact a little consideration will show that the curves of $H' = 0$, which correspond to each particular wind velocity, all lie in this region, and that the higher the wind velocity the nearer the curve lies to the isothermal of $36°{\cdot}5$. In Fig. 3 the dotted line is the curve of $H' = 0$, $V = 9$ m.p.s.

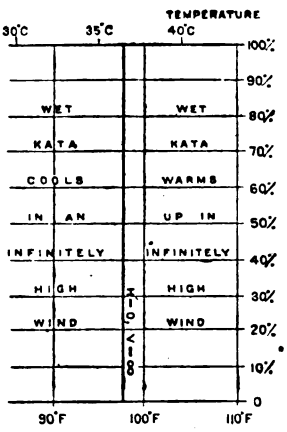

FIG. 2.—Wet katathermometer in an infinitely high wind.

The proper representation of $H' = 0$, *i.e.* of the division between the atmospheric conditions under which the wet-kata will heat up or will cool, is by a surface in a space model, the third axis of which corresponds to wind velocity. Fig. 1 really shows the section of this surface by the plane $V = 0$; the section by the plane $V = 9$ is the dotted curve of Fig. 3, and the surface asymptotically approaches the isothermal of $36°{\cdot}5$, as V becomes infinitely large.

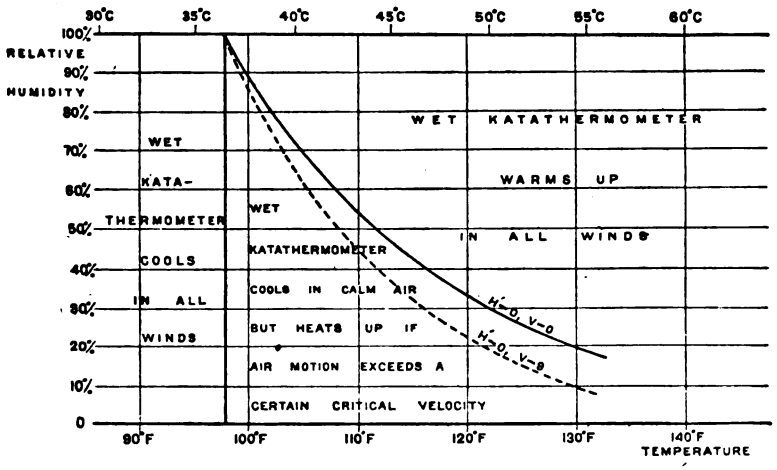

FIG. 3.—Wet katathermometer in winds of varying velocity.

5. APPLICATION OF WET-BULB FORMULA TO ESTIMATE UPPER CLIMATIC LIMIT.

Corroborative evidence to any conclusions from the kata formula may be expected from the wet-bulb formula, since the wet katathermometer, when $H' = 0$, is neither gaining nor losing heat, and should

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therefore be acting simply as a wet, large-bulbed thermometer. A suitable equation for a wet-bulb of the size of the wet-kata is

$$F - f = 0{\cdot}49(t - T)\left(1 + \frac{1}{1 + 3{\cdot}6\sqrt{V}}\right). \quad . \quad . \quad . \quad (4)$$

This is based upon theory and upon the experimental results of Sworykin and Belli.[1] As before, T is taken as 36°·5 C. and F as 45·4 mm. The curves of constant wet-bulb temperature 36°·5 for the wind velocities V = 0, V = 1, V = ∞ are plotted in Fig. 4. For all winds above 9 m.p.s. the wet-bulb curves are practically coincident.

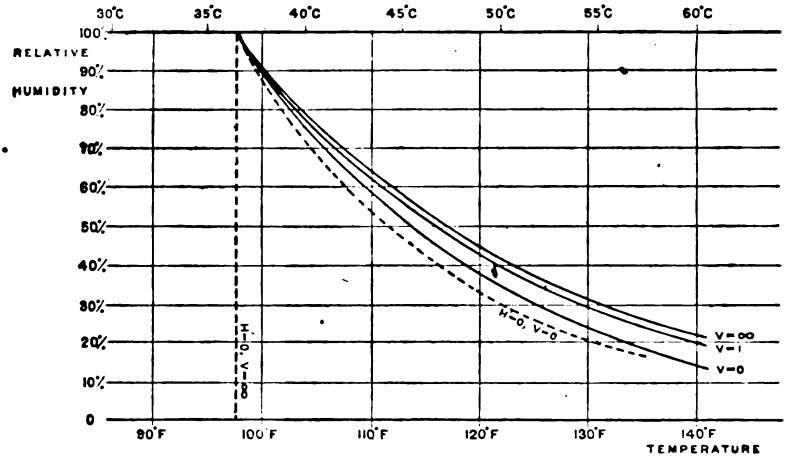

FIG. 4.—The three plain curves are those of constant wet-bulb temperature, 36°·5 C., in wind velocities of 0, 1, ∞ m.p.s. respectively.

6. COMPARISON OF RESULTS FROM WET-KATA AND WET-BULB FORMULAE.

On the same diagram the wet-kata curves of Fig. 3 have been reproduced to afford a ready comparison between the katathermometer and wet-bulb curves. Considering that we are really employing extrapolation methods in applying the katathermometer and wet-bulb formulae to temperatures above those used in the empirical determination of the formulae, we may state that the katathermometer and wet-bulb curves for a calm lie sufficiently close together to warrant no comment. But there is a wide divergence between the katathermometer and wet-bulb curves for high winds, and, more important still, these curves lie on different sides of the curves for a calm. What is the cause of this divergence, if the wet katathermometer, when it is neither gaining nor losing heat, might be expected to act exactly as a wet-bulb thermometer? We know that at lower wet-bulb temperatures at least the general wet-bulb formula represents the facts, viz., that in fixed conditions of air temperature and humidity a wind depresses the wet-bulb temperature. This is expressed in a diagram such as Fig. 4 by the wet-bulb curve for a wind being less steep than, and therefore lying to the right of, that

[1] Cf. Ferrel, *Report of Chief Signal Officer, Washington*, 1886, p. 236.

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for a calm. Why then do the katathermometer curves diverge increasingly from the wet-bulb curves as the wind velocity increases? The only explanation that strikes one is that the wet katathermometer does not evaporate as freely as a wet-bulb. The glove covering the bulb of the former is dipped in water at the beginning of an experiment, and after the real surface water has evaporated it would appear that the surface of the glove begins to dry and therefore the rate of evaporation becomes considerably reduced. This would account for the low value of the velocity index ($V^{0.8}$) found by Prof. Leonard Hill for the term in equation (2), that expresses the cooling power due to evaporation. On theoretical grounds, if evaporation is taking place as from a free water surface, we should expect the rate to be a function of $V^{0.5}$ in a steady wind, and of an even higher power of V, if the air motion is turbulent and the turbulence increases with the wind velocity.[1] From equations (1) and (4) we can in fact estimate the rate of evaporation from a wet large-bulbed thermometer, and this rate should be the same as that from a wet-kata, which is kept supplied with sufficient water. For by multiplying equation (4) throughout by the factor $[(1 + 3{\cdot}6\sqrt{V})/3{\cdot}6]$ we simply convert the wet-bulb equation into another form, namely,

$$(0{\cdot}27 + 0{\cdot}49\sqrt{V})(t - T) = (0{\cdot}28 + \sqrt{V})(F - f). \quad . \quad . \quad (5)$$

But we know from equation (1) that the left-hand side of this equation expresses the rate at which the thermometer is gaining heat by radiation and by convection and conduction from the air; it expresses in millicalories per sq. cm. per sec. the total gain of heat. The function on the right-hand side of the equation, viz. $(0{\cdot}28 + \sqrt{V})(F - f)$, must therefore represent the rate of heat loss, which is wholly due to evaporation. This suggests that if evaporation from the wet-kata were proceeding as freely as from a wet-bulb thermometer, the rate of heat loss from it would be expressed by the equation

$$H' = (0{\cdot}27 + 0{\cdot}49\sqrt{V})(T - t) + (0{\cdot}28 + \sqrt{V})(F - f) \quad . \quad . \quad (6)$$

instead of by equation (2).

7. Why it is preferable to base Conclusions upon the Wet-Bulb Formula.

To summarise the preceding paragraphs, the wet katathermometer and wet-bulb formulæ have furnished quite discordant results when applied to determine the conditions under which a wet surface at 36°·5 C. will heat up. Reasons have been given for ascribing this discrepancy to a less efficient wetting of the surface of the kata and to a consequently restricted rate of evaporation from it. It may with reason be contended that this fault of the wet-kata, if fault it can be called, is one on the right side. For in all ordinary climatic conditions the human body also adjusts its heat loss by restricting the rate of perspiration. When, however, conditions are near the upper limit for existence and the human body is fighting to keep its temperature down at its normal value, we must expect that the sweat glands will pour out

[1] Shierbeck, *Overs. over D. K. D. Vedensk. Selsk. Forh.*, 1896, No. 1. Jeffreys, *Phil. Mag., London*, 1918, p. 270.

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sweat and will strive to make the skin function as an efficient wet surface up to the point at which the glands can do no more, and the maximum rate of perspiration is reached. We therefore prefer to base any conclusion about the upper climatic limit for existence upon the results given by the wet-bulb formula rather than upon the wet-katathermometer equation.

8. A Wet-Bulb with a Limited Water-Supply.

Now by using the second form of the wet-bulb equation, namely, equation (5), we can not only derive the limiting conditions for a wet surface with unlimited evaporative powers, but can also readily see the result of adding the restriction that, though water may evaporate from the wet-bulb freely up to a certain maximum rate, it cannot be supplied to the bulb above this rate; this restriction corresponds to the inability of the human body to perspire beyond a definite maximum rate. To take an example, we have proved above that the rate of heat loss (E) due to evaporation at any point (t, f) on a wet-bulb curve is

$$E = (0{\cdot}28 + \sqrt{V})(F - f) = (0{\cdot}27 + 0{\cdot}49\sqrt{V})(t - T). \quad . \quad (5')$$

In Fig. 5 is reproduced the wet-bulb curve of 36°·5 C., when the bulb is ventilated by a wind of 9 m.p.s. At the points A, B, C, D along the curve, where the air temperatures are 36°·5, 45°, 53°·7, and 60° C. respectively, the rates of heat loss by evaporation are 0, 14·8, 30, 40·9 milli-calories per cm.^{2} per sec.

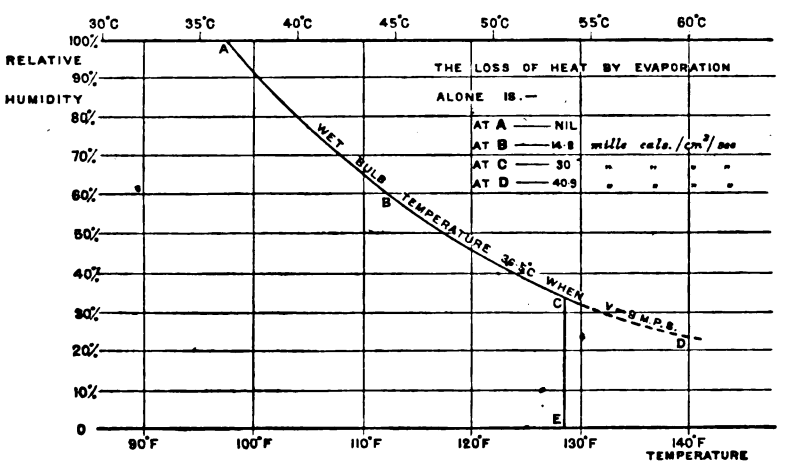

Fig. 5.—Graph of constant wet-bulb temperature 36°·5 C. when wind velocity is 9 m.p.s. and evaporation is restricted to a certain maximum rate.

Now let us assume that the rate of heat-loss by evaporation is restricted to a maximum value of $E_m = 30$ milli-calories per cm.^{2} per sec. Then obviously the wet-bulb curve of 36°·5 C., when V = 9 m.p.s., must have a discontinuity at the point C, where the rate of heat-loss by evaporation reaches this maximum value. Beyond this point the wet-bulb equation (5) becomes

$$(0{\cdot}27 + 0{\cdot}49\sqrt{V})(t_m - 36{\cdot}5) = 30, \quad . \quad . \quad . \quad (7)$$

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i.e. since V = 9, the remaining portion of the curve is simply the isothermal $t = 53°{\cdot}7$ C., and the complete curve is no longer A B C D, which corresponds to unrestricted evaporation, but A B C E. Similarly in the general case it is obvious that the wet-bulb curve corresponding to any velocity, V, is composed of two parts; one part lies along that of the ordinary wet-bulb curve up to the point where the air temperature is $t_m = 36{\cdot}5 + E_m/(0{\cdot}27 + 0{\cdot}49\sqrt{V})$; the remainder is the isothermal t_m. Values of t_m for different values of V, when $E_m = 30$, are as follows:

V =	1	4	9	16	25	m.p.s.
t_m =	76°·0	60°·5	53°·7	49°·9	47°·5	C.

The wet-bulb curves, thus modified, of 36°·5 C. for varying wind velocities are plotted in Fig. 6, and it need hardly be emphasised that these curves should be imagined as sections of a surface in a space model

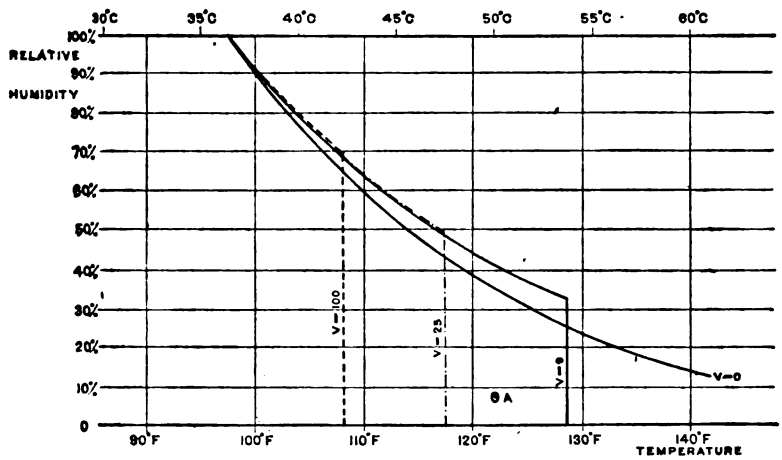

FIG. 6.—Curves of constant wet-bulb temperature 36°·5 for wind velocities of 0, 9, 25, 100 m.p.s. when evaporation from bulb is restricted to a certain maximum rate.

n which the third axis is wind velocity.[1] The surface would signify, briefly, this—that a wet body of the size of a katathermometer bulb, which has a temperature of 36°·5 C. and a maximum evaporative capacity of 30/L milligrams per cm.^{2} per sec. and is shaded from the sun, will heat up or will cool according to whether the point representing the temperature, humidity, and wind conditions of the moment lies on the right- or on the left-hand side of the surface.[2]

If now in addition we suppose that the wet-bulb can exist only at a temperature of 36°·5 C., but has a source of heat upon which it can draw at will, then the curves of Fig. 6 define its limit of existence, for if the air conditions lie to the left of the appropriate curve

[1] The net rate of heat loss at any point (t, f, V) in the neighbourhood of the surface will be (1) if, $(0{\cdot}28) + \sqrt{V}(F - f) \leqslant 30$

$$H' = (0{\cdot}28 + \sqrt{V})(F - f) - (0{\cdot}27 + 0{\cdot}49\sqrt{V})(t - T),$$

but (2) if $(0{\cdot}28) + \sqrt{V}(F - f) > 30$

$$H' = 30 - (0{\cdot}27 + 0{\cdot}49\sqrt{V})(t - T).$$

[2] Where L = latent heat of evaporation.

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for the prevailing wind, the wet-bulb will draw upon its source of heat and continue to exist, while if the air conditions lie to the right it must warm up and cease to exist.

9. Application to the Human Body.

Now how far are the above results applicable to the human body? We have first the physiological facts—

(1) Life ceases to exist, if the body temperature rises above 36°·5 C. (see last sentence, § 1, above.)

(2) The body can supply its surface with water up to a certain maximum rate.

(3) The body can draw upon a reserve of heat by increasing its metabolic processes.

Thus the body is similar in these respects to our wet-bulb thermometer, and therefore its conditions of existence would be defined by curves similar to those of Fig. 6 ; but there are further the following modifications to consider :

(*a*) The size of man contrasted with the bulb of a katathermometer.

(*b*) The minimum value of the production of heat in man, since so long as life continues this heat production cannot be reduced to zero.

(*c*) Sun's radiation, if the man is out of doors.

(*d*) Man's maximum rate of perspiration.

The modifications in the curves which will result from (*a*), (*b*), and (*c*) are all likely to be in the same direction, namely, a displacement of the curves to the left, *i.e.* towards lower values of t and f; but these displacements will only be slight for the higher values of V, and will increase as V diminishes. This consequence as regards (*a*) may be verified by calling to mind our knowledge of the effect of increasing the size of the bulb of a wet thermometer; the effect is to increase the divergence of the curves for, say, V = 0 and V = 1 in Fig. (4) from that for V = ∞, while leaving the curves for high wind velocities practically unaltered. The modifications resulting from (*b*) and (*c*) can be gauged by forming an estimate of the effect which an additional source of heat would have on the wet bulb. The limiting curves would then be given, not as before by

$$(0{\cdot}27 + 0{\cdot}49\sqrt{\mathrm{V}})\,(\mathrm{T} - t) + (0{\cdot}28 + \sqrt{\mathrm{V}})(\mathrm{F} - f) = 0, \quad . \quad (5)$$

but by

$$(0{\cdot}27 + 0{\cdot}49\sqrt{\mathrm{V}})\,(\mathrm{T} - t) + (0{\cdot}28 + \sqrt{\mathrm{V}})(\mathrm{F} - f) = \mathrm{R}, \quad . \quad (8)$$

where R is a positive quantity equal to the rate of gain of heat by (*b*) and (*c*). Substituting t' for $[t + \mathrm{R}/(0{\cdot}27 + 0{\cdot}49\sqrt{\mathrm{V}})]$ equation (8) transforms into an equation exactly similar to equation (5), which shows that the curves of Fig. 6 require only to be displaced to the left by an amount $[\mathrm{R}/(0{\cdot}27 + 0{\cdot}49\sqrt{\mathrm{V}})]$°C., *i.e.* by an amount which decreases as the velocity rises. So far then as the modifications produced by (*a*), (*b*), and (*c*) are concerned, we have good reason for considering that the curves in Fig. 6 give too high values of the limit for human existence, the more so the lighter the wind.

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It is easy to see how the curves of Fig. 6 will be modified on account of (d), the maximum rate of perspiration in man. If the rate of water supply to the wet-bulb, on which Fig. 6 is based, is higher than corresponds to the maximum rate of evaporation in man, then the only adjustment required is a displacement of the isothermal portions of each curve in Fig. 6 towards the left; if the assumed rate of water supply is too low, the displacement must be towards the right. Also the displacements must be such that the temperature t_m of these isothermal portions must be related to the wind velocity in an exactly similar way, as we have seen to hold in the case of the wet-bulb, namely, $t_m - 36{\cdot}5 = (E_m - R)/(\alpha + \beta\sqrt{V})$. I am not aware of any data which will help to decide the true position of the isothermal portions for the case of the average man. There is also this point to be noted, that the maximum rate of perspiration is not a constant quantity for all men, but varies from individual to individual, and even with the momentary condition of the individual.

Until data are available, however, for the definition of the actual position of these isothermal portions for the case of the average healthy man, they may be provisionally defined as in Fig. 6. Granting this proviso in addition to our earlier assumption that atmospheric conditions resulting in a net gain of heat to the human body must be fatal, we may conclude that the curves of Fig. 6 exhibit the extreme upper limits of livable climatic conditions.

10. The Simoom and Heat-Strokes.

To return now to our starting point, the question of the simoom, it is easy to see from Fig. 6 how the sudden onset of a high wind may convert livable conditions into conditions that are beyond the limit for existence. Consider the point A on Fig. 6 ($t = 122°$ F., humidity 8 per cent, a value which may occur in a hot desert on a day of light wind). The result of a sudden rise in the wind velocity from 9 m.p.s. to 25 m.p.s. is clear from the diagram; the conditions are supportable in the former case but not in the latter, the critical wind velocity being about 15 m.p.s. I am inclined to think that just such an explanation will be found to be sufficient for all fatal simoom effects, and that there will be no necessity for calling in the aid of the unknown factors demanded by Blanford.

A word may be added about heat-strokes. These occur in conditions that are apparently quite supportable, since only a small number of persons are afflicted. The essential feature of them may, however, be that a portion of the body has for a time been exposed to air conditions which are above the limit for existence. For example, as a result partly of the sun's heat on the helmet or on the clothes, and partly of bad ventilation of the air in the helmet or next the skin, the head and spine may have been exposed for a time to air at, say, 40° C. and 80 per cent humidity, *i.e.* above the limit for existence. The normal healthy body may be able to fight such conditions and suffer only from a "touch of the sun," while a less fit man's mechanism may be thrown completely out of gear, like the upsetting of a system in unstable equilibrium, and heat-stroke result.

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DISCUSSION.

Dr. LEONARD HILL, after congratulating Lieut. Normand on his interesting and suggestive paper, pointed out that the katathermometer was introduced in order to measure cooling and evaporation in comfortable and uncomfortable conditions. The formulae were worked out afterwards as a secondary purpose in order to be able to derive from the published meteorological data on wind and temperature what would be the cooling and evaporative powers in different climates, *vide* vol. I. of his "Report to the Medical Research Committee on Science of Ventilation and Open-Air Treatment." The formula worked out for the wet-kata was based on observations taken in wind tunnels at temperatures below the body temperature, and he was unable to say whether the formula held for the temperatures considered by Lieut. Normand. Lieut. Normand had suggested that the reason why the theoretical katathermometer and wet-bulb curves diverged at temperatures above body temperature, as the wind velocity increased, was that the surface of the glove of the katathermometer began to dry and evaporation was reduced. He did not think the error came in from the drying of the glove of the wet katathermometer, but would suggest that "sheltering" came in in these large-bulb thermometers, and this was obviously greater in the case of the human body. There was, he thought, no experimental evidence that the wet-bulb formula held good for bulbs of large size. In considering heat-stroke it must be borne in mind that there are some 70 kilogrammes of wet-body substance which have to be heated up. Further, not only evaporation from the skin but from the lungs was under control. The cause of heat-stroke was fatigue and exhaustion of the sweat glands. This was proved in Mesopotamia by G. K. Hearn, who found that in going round his wards he could identify all the men who were going to have heat-stroke by feeling the bodies of the men which were dry. When the air temperature was above body temperature these men wanted the fans removed. By putting on wet sheets and spraying them with water Hearn was able to stop all danger of heat-stroke, because the wet sheets properly sprayed took the place of sweating. Exhaustion of sweating was much more likely to occur in the case of unfit persons there, who had malaria, or suffered from constipation or any bacterial toxin. The sun's heat was very important. He had calculated that the heat production of a man resting was one milli-calorie per square centimetre per second; work could add another three, the sun another ten to this. Pith helmets, spinal pads, white garments were required to keep off the sun.

Capt. R. C. T. EVANS, R.A.M.C., said that his Persian servant had told him that the way to minimise the danger from the simoom was to lie down and bury the head, hands and feet in the clothing, because the clothes prevented the burning hot sand and wind from touching the skin. If the simoom did not last more than an hour or two some lives were saved. He understood that this confirmed Lieut. Normand's contention,[1] because by the interposition of the partial non-conductor of heat, which is also a partially porous substance, the following events occur contemporaneously. The body is partially protected from the temperature of the wind, and more important, from the velocity of the wind. Say that the porosity allows $\frac{1}{4}$ of the wind which blows against the crouching form to penetrate clothes and blow through the encircling layers of clothes and out of the leeward side; it almost certainly would be of very low humidity, and on the whole its effects would be cooling, or anyway there would be nothing like the rapid heating up which would occur if the skin were exposed.

Now, although the internal generation of heat by the body must go on

[1] The contention was, so he understood, that for a particular individual, and for any given humidity and temperature, there is a critical wind velocity at which the gain of heat balances the loss. This velocity and any velocity above it is highly dangerous.

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while life lasts (in the higher forms of life), yet in the case considered, the heat capacity of the human body is such that it would take an hour or two for the two heats, the internal formation and mitigated inflow from the wind penetrating through the clothes, to raise the temperature above one which is still compatible with life, at least temporarily, say 110°-111° F. (patients have recovered from such). In the hot summer of 1917 in Basra he had observed a very interesting natural experiment as to the different powers of various human bodies to withstand high temperature. In July to August the maximum temperature went up in steps: for instance, from 100 to 105° F., where it remained some five to six days; then in one day to 110°, where it remained again constant for a similar period; then to 115°, followed by a four or five days' level temperature, and finally to 121°·5 F., when it stayed eight to ten days. On the first day or two of each "step up" of 5° a rush of heat-strokes occurred. For the remainder of each level temperature only a sporadic case or two happened, then the first day or two of the next higher level another crop of heat-strokes occurred, and so on. He considered that this showed that for each individual there was a critical air temperature (under any particular condition) above which he could not live. He wished to draw attention to the article on "Effects of Heat" in Manson's *Book of Tropical Medicine*, describing Heat Exhaustion, Insolation (direct exposure of head or back to sun), and Heat-Stroke, the last being the only important one, of very localised incidence and very fatal. He threw out only as a suggestion that in some cases the heat-controlling centre in the brain became "out of gear," and failed to control the temperature. It was only when the temperature of the body became lowered below a certain figure by cold bathing that the mechanism geared in again.

Lt.-Col. M. FLACK, C.B.E., R.A.F., said he was not going to talk about the subject from the point of view of heat but from that of airmen at altitudes where high wind and intense cold had to be considered. Under the latter conditions the vital capacity was one of the important things that differentiated the fit man from the unfit. Instead of a vital capacity of 4800 c.c. which a fit man might have, the same man unfit might have only 3600 c.c. It was not the power to breathe in that was lost but the effective power to breathe out. How much the wind contributed to that he did not know, but he believed it did considerably. He suggested that one of the explanations of why one man got heat-stroke and not another was because the fit man had a good vital capacity and was able to lose a large percentage of water from his lungs which would help greatly. The man who was fatigued had a very poor expiratory force, low vital capacity, and could not bring the same degree of lung evaporation into play and so went under. He believed a stuffy atmosphere and sedentary life brought about a diminution of expiratory force and loss of abdominal tone which reacted deleteriously on the human subject.

Lieut. C. W. B. NORMAND in reply said that there was very little for a meteorologist to reply to, and he felt quite unable to deal with the medical part of the discussion. He was sorry to seem to make an indictment, as the Chairman had suggested, about Dr. Leonard Hill's katathermometer formula. He realised, and had emphasised in his paper, that his work was mainly theoretical, and he simply had suggested that the cause of the discrepancy between the wet-bulb and the wet katathermometer was less efficient evaporation from the latter, because when he had had an opportunity of seeing a wet katathermometer at Baghdad early in the year the katathermometer seemed much drier than the wet-bulb and did not seem to glisten with water as the wet-bulb did. He could not answer off-hand the suggestion that the sheltering effect of a large bulb might explain the discrepancy, but did not imagine that it would, since experiments have proved that the same wet-bulb formula served for bulbs of all sizes, provided the ventilation was brisk enough.

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Dr. LEONARD HILL writes on January 28: Since the discussion, I have studied the drying of a wet katathermometer which was heated electrically, a suitable wire being introduced within the bulb. Four successive readings taken after a single wetting gave concordant results and disproved the theory of drying. I found, however, that the cooling times were nearly 20 per cent shorter in the case of the electrically heated kata owing to the cooling of the glove by evaporation during heating, a fact which shows that the wet-kata cannot be considered theoretically as a wet-bulb thermometer, and must be heated in water at about 80° C., as directed, in order to be used as an empirical measure of comfortable and healthy conditions of atmosphere.

Fluctuations of the Underground Water-Level.

The question of the periodical fluctuations of the water-level in wells and porous rocks has often been brought before the Society, and the importance of a knowledge of the regime of these variations during the war is well brought out in a paper by Capt. W. B. R. King on the geological work on the Western Front, printed in the *Geographical Journal* for October 1919. Both in the matter of water-supply and in the construction of the very extensive system of mine galleries which were excavated in the chalk, it was of great importance to be able to forecast the height of the water-table at different seasons of the year. The relation of the water-level to rainfall was accordingly studied, and it was realised how little effect the summer rains have on the level, owing to the more abundant evaporation, and how the maximum height of the water is to be expected towards the spring. As a result of this investigation a number of fresh galleries were constructed at a higher elevation, which prevented a large part of our mining system from being flooded out and lost.

Lenticular Cirro-Cumulus Cloud.

On looking up my cloud records I find that the above form, described by Mr. Granger as occurring at Nottingham on June 11, 1919 (*Quarterly Journal*, October 1919, p. 338), was seen at Dorking, Surrey, on the same date. Cirro-cumulus formed in the south-west, between 16.00 and 16.30 G.M.T., the sky being $\frac{6}{10}$ covered at 17.30. Cirro-cumulus lenticularis became visible at 18.15, being confined to the western area of the sky, remaining in evidence for nearly an hour. At 19.00, in the neighbourhood of the sun, brilliant iridescence was visible, the green and red colours predominating. The sky became entirely cloudless by 20.30. This form of cloud is undoubtedly of an uncommon type, but, during the past two years, I have the following records of it: September 15, 1918, 20.00, Dorking, Surrey; October 4, 1918, 07.15, Tadworth, Surrey, with bright prismatic colours at 07.45. Again, on October 24, 1918, at 15.00 in London, markedly iridescent. During 1919 it was noted in London on January 3 at 09.00, June 5, 13.00, and October 21 at 16.00, showing rainbow-coloured tints on the latter date. With the exceptions of June 5 and October 21, 1919, rain has followed the appearance of this cloud within 12-24 hours.

SPENCER C. RUSSELL.

ADMIRALTY,
November 18, 1919.

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SOME OBSERVATIONS OF THE UPPER AIR OVER PALESTINE.

By Captain A. J. BAMFORD, M.C., M.G.C., F.R.Met.Soc.

[Received October 8—Read November 19, 1919.]

1. The following tables and graphs summarise the results of some upper air observations made over Palestine between September 1917 and January 1919.

These observations were made in the first place for current military purposes, and in regrouping the material they contain in order to look at it from a rather different aspect, this point will be emphasised more than once, *e.g.* in the choice of hours of observation.

2. The figures are taken from flights observed initially with two instruments (usually for 15 minutes). For the remainder of the ascent a uniform vertical velocity was assumed, and only one theodolite used.

Until the middle of July 1918 the second instrument was also a theodolite, whose distance from the first, usually about a kilometre, had to be measured, but after that a rangefinder was used, thus eliminating the second station and its field telephone, while retaining a direct determination of the altitude of the balloon in the early part of its flight. In cases where the balloon travelled consistently and rapidly in one direction it was not desirable to use the rangefinder for as long as fifteen minutes, but even then it was in use during the first few minutes, *i.e.* in the part of the flight where there was most reason to expect that the rate of rise would be erratic. The rangefinder was found to make a rather bigger demand on the observer than the theodolite did, and if not properly adjusted and handled could be a positive menace, but fortunately several observers were available who were quite experienced in its use.

3. The station near Ramleh was in use for just over a year, and supplies material for Tables I. and II., which give the monthly averages of the West to East, and South to North components respectively, at each successive 1000 feet height. The number of observations contributing to each average is noted alongside.

Tables III. to VI. give similar information for a few months at Jerusalem and at a place near Khan Yunus called Kelab.

4. The matter of these Tables is shown more clearly in graphical form. Looking at Figs. 1 and 2, it is noticeable that the West to East direction is dominant throughout, and that in the neighbourhood of 10,000 feet the greatest velocity is reached in April, after which there is a steady fall off till October. The transition from one month to the next is usually smooth, the sharpest change being from January to February 1918. However, as observations were only taken during half of January 1918, and these do not correspond at all to the average of January 1919, too much attention should not be paid to the former month.

In the South to North graph there is far more variation in sign, and the most conspicuous piece of continuity is the way in which the dis-

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tribution from July to October is consistently negative in the lower and positive in the upper layers, with the altitude of division getting steadily lower each month. It is noteworthy that these variations do not appear to be symmetrical. Here, too, January 1918 appears abnormal.

TABLE I.—West to East Component.

Station Ramleh. Time 12.00 (noon).

Number of observations and mean velocity in miles per hour at intervals of 1000 feet. January to June 1918.

Month.	January.		February.		March.		April.		May.		June.	
Altitude in thousands of feet.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	15	−3	24	+3	30	+5	30	+8	31	+8	30	+9
2	15	−2	24	+4	30	+7	30	+5	31	+6	30	+6
3	15	−3	20	+2	28	+6	29	+2	31	+3	30	+3
4	14	−4	17	+2	24	+6	29	+4	31	+3	29	+3
5	13	−6	17	+5	18	+4	28	+6	30	+4	29	+5
6	13	−6	13	+6	17	+7	27	+8	30	+7	29	+7
7	10	−7	13	+8	15	+12	25	+10	28	+10	29	+7
8	10	−5	9	+9	13	+14	21	+10	27	+11	29	+9
9	10	−8	9	+14	12	+16	20	+14	27	+12	28	+9
10	10	−8	5	+14	11	+17	17	+14	24	+13	27	+10
11	10	−8	4	+14	8	+18	15	+19	20	+16	24	+12
12	8	−7	4	+18	7	+21	12	+20	17	+18	24	+13
13	8	−3	3	+13	5	+17	12	+20	15	+16	21	+13
14	8	−6	3	+7	4	+14	11	+24	15	+18	20	+14
15	8	−5	3	+9	3	+15	11	+24	14	+19	17	+12
16	7	−6	3	+26	3	+20	8	+23	13	+20	16	+13
17	5	−4	3	+32	2	+19	4	+10	11	+16	14	+13
18	2	+7	1	+25	1	+8	2	+15	10	+15	8	+18
19	...		...		1	+32	2	+13	9	+15	5	+20
20	...		...		1	+45	2	+17	6	+13	5	+21
21	...		...		...		2	+22	4	+9	4	+22
22	...		...		...		2	+24	4	+18	4	+26
23	...		...		...		1	+23	4	+21	2	+19
24	...		...		...		1	+28	4	+27	2	+22
25	...		...		...		...		2	+10	1	+20
26	...		...		...		...		1	+18	1	+16
27	...		...		...		...		1	+18	1	+18
28	...		...		...		...		1	+21	1	+18
29	...		...		...		...		...		...	
30	...		...		...		...		...		...	

5. The Jerusalem observations, Tables III. and IV., are only available for two months. They were not taken at the same time of day as the Ramleh ones, and it is worth noticing that the afternoon readings at Jerusalem agree much better than the morning ones with the mid-day readings nearer the coast, particularly in the case of the West to East component. Details are shown in Fig. 3.

6. Observations at Kelab in September to November 1917 are shown in Tables V. and VI., and Fig. 4. Table V. shows a general simi-

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larity to the West to East components elsewhere. Table VI. gives three monthly averages of the South to North component, though the observations in Sept. and Nov. were confined to the latter and earlier halves of those months respectively. The same reversal of direction is noticeable

TABLE I. (*continued*).—West to East Component.

Station Ramleh. Time 12.00 (noon).

Number of observations and mean velocity in miles per hour at intervals of 1000 feet. July 1918 to January 1919.

Month.	July.		August.		September.		October.		November.		December.		January.	
Altitude in thousands of feet.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	31	+ 9	31	+11	29	+ 8	31	+ 6	30	+ 4	28	+ 6	24	+ 4
2	31	+ 5	31	+ 6	29	+ 6	31	+ 0	30	+ 3	28	+ 7	22	+ 3
3	31	+ 2	31	+ 3	28	− 1	31	− 1	29	+ 2	27	+ 7	21	+ 3
4	31	+ 2	31	+ 3	27	− 1	31	− 1	27	+ 2	25	+ 7	18	+ 1
5	31	+ 5	30	+ 4	23	+ 4	31	+ 1	26	+ 5	23	+ 7	17	+ 3
6	31	+ 6	30	+ 5	23	+ 5	28	+ 1	25	+ 8	21	+ 9	15	+ 4
7	31	+ 8	24	+ 7	20	+ 5	28	+ 2	23	+ 7	20	+10	13	+ 7
8	30	+11	23	+ 8	20	+ 5	25	+ 3	20	+ 7	19	+14	12	+ 6
9	29	+13	20	+ 9	19	+ 5	24	+ 3	19	+ 8	16	+18	9	+ 9
10	27	+13	19	+ 9	18	+ 5	23	+ 4	19	+11	13	+18	8	+14
11	26	+13	15	+10	15	+ 3	22	+ 5	16	+11	11	+15	6	+16
12	26	+14	14	+ 9	14	+ 6	19	+ 6	15	+11	9	+17	5	+18
13	26	+15	14	+ 9	12	+ 6	19	+ 5	15	+13	8	+19	4	+14
14	25	+13	13	+ 9	10	+ 9	18	+ 6	9	+14	6	+17	4	+14
15	24	+11	11	+10	8	+ 6	18	+ 5	8	+14	4	+16	3	+15
16	24	+10	11	+14	8	+ 7	15	+ 7	7	+15	2	+ 6	2	+15
17	22	+10	9	+15	6	+10	14	+ 7	3	+10	2	+ 7	1	+14
18	17	+10	9	+17	6	+11	12	+ 9	2	+ 6	...		1	+18
19	15	+12	7	+18	4	+ 7	4	+17	...		...		...	
20	15	+13	5	+14	3	+ 3	3	+ 7	...		...		...	
21	14	+13	5	+14	2	+ 8	3	+ 4	...		...		...	
22	12	+16	4	+13	2	+15	1	+ 4	...		...		...	
23	10	+12	2	+12	1	+ 6	...		...		...		..	
24	10	+13	2	+13	1	+ 8	...		...		...		...	
25	9	+19	1	+14	1	+21	...		...		...		...	
26	8	+24	1	+11	...		...		...		...		...	
27	7	+29	1	+ 8	...		...		...		...		...	
28	6	+28	1	+12	...		...		...		...		...	
29	3	+24	1	+11	...		...		...		...		...	
30	...		1	+ 8	...		...		...		...		...	

here as in the corresponding months of the next year at Ramleh, though the height of reversal is a little greater at the more southern station.

7. Fig. 5 is obtained by combining the two rectangular components, and so looking at directions in plan. This demonstrates the changes in direction both from one altitude to another in any particular month, and from one month to another at any particular altitude. Observations have been grouped in layers of 3000 feet, and a rough classification is to say that there is a general tendency to back during the summer, and

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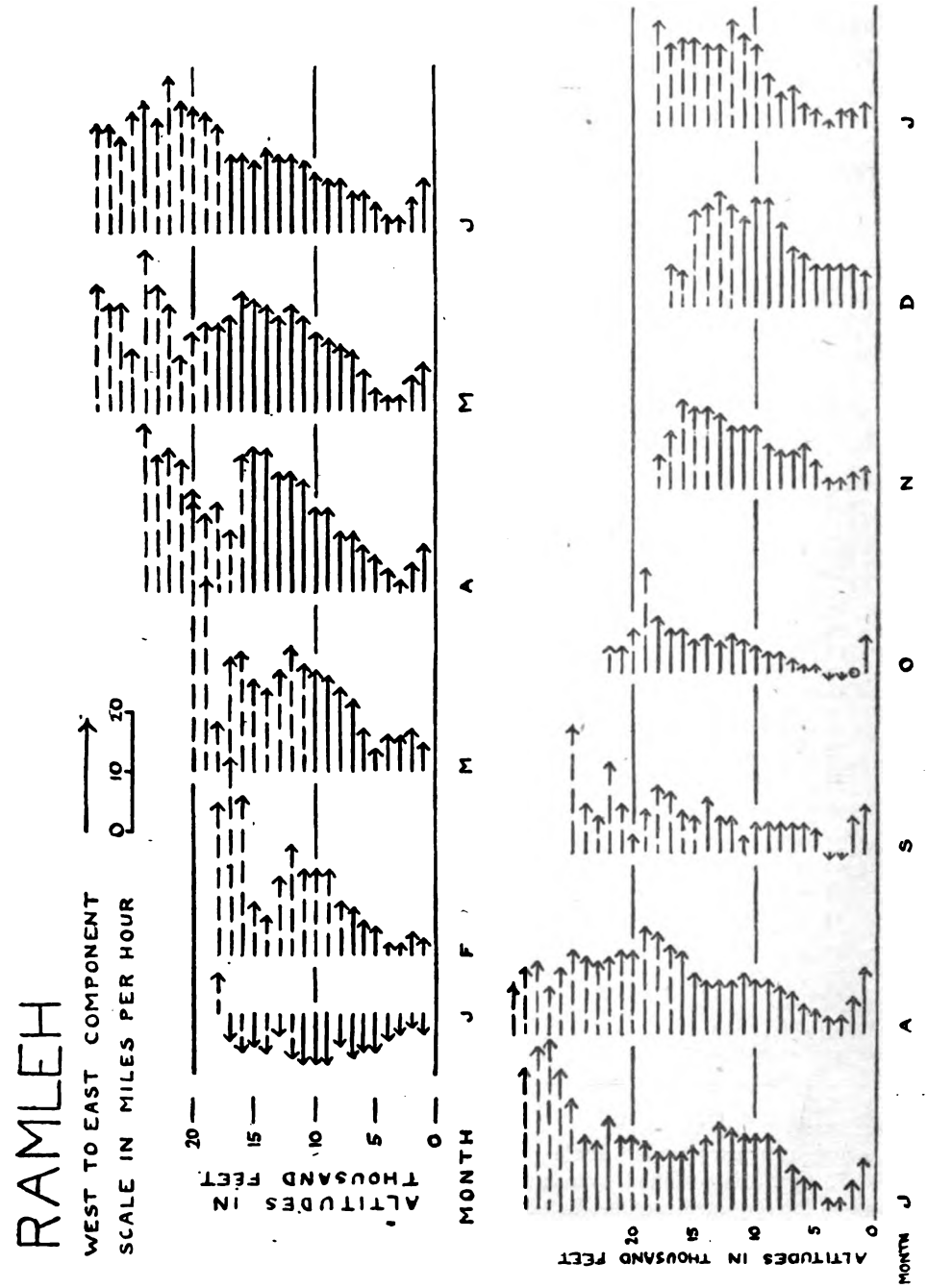

FIG. 1.—Monthly Averages of Velocity at Various Altitudes.
Arrows are shown with broken shafts if derived from less than ten observations.

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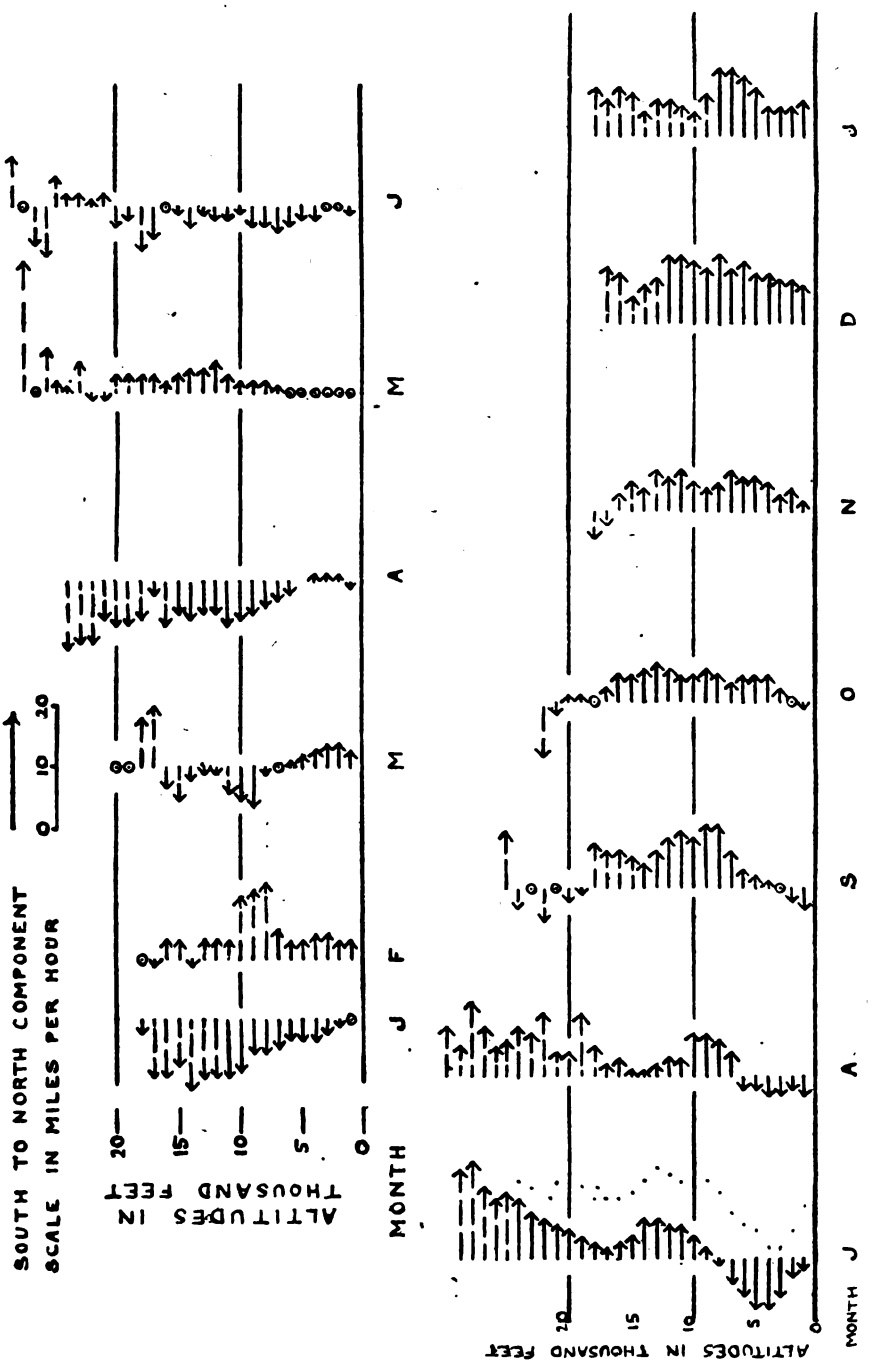
SOUTH TO NORTH COMPONENT
SCALE IN MILES PER HOUR
0 10 20
ALTITUDES IN THOUSAND FEET
20 15 10 5 0
MONTH
J F M A M J
ALTITUDES IN THOUSAND FEET
20 15 10 5 0
MONTH
J A S O N D J

FIG. 2.—Ramleh. Monthly Averages of Velocity at Various Altitudes. Arrows are shown with broken shafts if derived from less than ten observations.

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veer during the winter. June is an exception to the above, except above 20,000 feet. The changes from one type to the other usually occur about the end of April and September.

8. Looked at from the point of view of variation with altitude, the

TABLE II.—South to North Component.

Station Ramleh. Time 12.00 (noon).

Number of observations and mean velocity in miles per hour at intervals of 1000 feet. January to June 1918.

Month.	January.		February.		March.		April.		May.		June.	
Altitude in thousands of feet.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	15	0	24	+ 3	30	+ 3	30	− 1	31	0	30	− 1
2	15	− 1	24	+ 3	30	+ 4	30	+ 1	31	0	30	0
3	15	− 2	20	+ 4	28	+ 4	29	+ 1	31	0	30	0
4	14	− 3	17	+ 4	24	+ 3	29	+ 1	31	0	29	− 2
5	13	− 3	17	+ 3	18	+ 2	28	0	30	0	29	− 2
6	13	− 3	13	+ 3	17	+ 1	27	− 2	30	0	29	− 3
7	10	− 4	13	+ 5	15	+ 0	25	− 3	28	+ 1	29	− 4
8	10	− 5	9	+12	13	− 1	21	− 4	27	+ 2	29	− 3
9	10	− 5	9	+11	12	− 6	20	− 5	27	+ 2	28	− 3
10	10	− 8	5	+10	11	− 5	17	− 6	24	+ 2	27	− 1
11	10	− 9	4	+ 3	8	− 4	15	− 7	20	+ 3	24	− 2
12	8	− 9	4	+ 3	7	− 1	12	− 5	17	+ 5	24	− 2
13	8	− 9	3	+ 3	5	− 1	12	− 5	15	+ 4	21	− 1
14	8	−11	3	− 1	4	− 2	12	− 6	15	+ 4	20	− 3
15	8	− 7	3	+ 3	3	− 5	11	− 5	14	+ 3	17	− 1
16	7	− 9	3	+ 3	3	− 3	8	− 7	13	+ 2	16	0
17	5	− 9	3	− 1	2	+10	4	− 2	11	+ 3	14	− 5
18	2	− 2	1	0	1	+ 8	2	− 6	10	+ 3	8	− 7
19	...		...		1	0	2	− 7	9	+ 3	5	− 2
20	...		...		1	0	2	− 7	6	+ 3	5	− 3
21	...		...		...		2	− 6	4	− 1	4	+ 2
22	...		...		...		2	−10	4	− 1	4	+ 1
23	...		...		...		1	−10	4	+ 5	2	+ 2
24	...		...		...		1	−11	4	+ 1	2	+ 2
25	...		...		...		...		2	+ 2	2	+ 5
26	...		...		...		...		1	+ 7	1	− 8
27	...		...		...		...		1	0	1	− 6
28	...		...		...		...		1	+21	1	0
29	...		...		...		...		...		1	+ 8
30	...		...		...		...		...		...	

most noticeable feature is the way that the angular amount of these changes in direction decreases with altitude. In the 4-6000 layer averages vary from NNW (July) to S (Oct.), but above 20,000 everything is included between WNW and WSW.

9. In dealing with so short a period it is useless to try to build up much of a theory of distribution from what may subsequently be shown by future observations to be an abnormal year. However, in view of the paucity of information available on this subject at present, it seemed

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worth while to publish these figures for what they are worth, and at the same time it is interesting to see how far the Palestine observations fit in with such general ideas as have been formulated on the basis of observations elsewhere.

TABLE II. (*continued*).—SOUTH TO NORTH COMPONENT.

Station RAMLEH. Time 12.00 (noon).

Number of observations and mean velocity in miles per hour at intervals of 1000 feet. July 1918 to January 1919.

MONTH.	July.		August.		September.		October.		November.		December.		January.	
Altitude in thousands of feet.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	31	− 2	31	− 3	29	− 3	31	− 1	30	+ 2	28	+ 6	24	+ 6
2	31	− 3	31	− 2	29	− 2	31	0	30	+ 4	28	+ 7	22	+ 5
3	31	− 6	31	− 3	28	0	31	+ 2	29	+ 3	27	+ 7	21	+ 5
4	31	− 8	31	− 3	27	+ 1	31	+ 4	27	+ 5	25	+ 8	18	+ 5
5	31	− 8	30	− 2	23	+ 2	31	+ 4	26	+ 6	23	+ 8	17	+ 8
6	31	− 6	30	− 2	23	+ 3	28	+ 4	25	+ 6	21	+10	15	+10
7	31	− 4	24	+ 4	20	+ 6	28	+ 3	23	+ 7	20	+ 9	13	+11
8	30	− 1	23	+ 6	20	+10	25	+ 4	20	+ 5	19	+11	12	+11
9	29	+ 2	20	+ 7	19	+10	24	+ 5	19	+ 4	16	+ 9	9	+ 7
10	27	+ 4	19	+ 7	18	+ 8	23	+ 4	19	+ 5	13	+10	8	+ 4
11	26	+ 6	15	+ 3	15	+ 9	22	+ 4	16	+ 7	11	+11	6	+ 5
12	26	+ 6	14	+ 3	14	+ 8	19	+ 5	15	+ 6	9	+11	5	+ 6
13	26	+ 7	14	+ 2	12	+ 6	19	+ 6	15	+ 7	8	+ 7	4	+ 6
14	25	+ 7	13	+ 1	10	+ 4	18	+ 5	9	+ 4	6	+ 6	4	+ 4
15	24	+ 4	11	+ 1	8	+ 5	18	+ 4	8	+ 5	4	+ 4	3	+ 7
16	24	+ 3	11	+ 3	8	+ 6	15	+ 4	7	+ 3	2	+ 8	2	+ 8
17	22	+ 2	9	+ 2	6	+ 6	14	+ 2	3	− 2	2	+ 9	1	+ 6
18	17	+ 3	9	+ 5	6	+ 7	12	0	2	− 4	...		1	+ 8
19	15	+ 4	6	+10	4	− 1	4	+ 1	...		...		...	
20	15	+ 5	5	+ 4	3	− 2	3	+ 1	...		...		...	
21	14	+ 6	5	+ 4	2	0	2	− 2	...		...		...	
22	12	+ 7	4	+10	2	− 5	1	− 9	...		...		...	
23	10	+ 8	2	+ 7	1	0	...		...		...		...	
24	10	+10	2	+ 8	1	− 3	...		...		...		...	
25	9	+11	1	+ 6	1	+ 9	...		...		...		...	
26	8	+10	1	+ 5	...		...		...		...		...	
27	7	+12	1	+ 8	...		...		...		...		...	
28	6	+16	1	+12	...		...		...		...		...	
29	3	+15	1	+ 5	...		...		...		...		...	
30	...		1	+ 8	...		...		...		...		...	

Hildebrandsson's *Résultats des Recherches Empiriques sur les Mouvements Généraux de l'Atmosphère* concludes with a summary of "conclusions générales," with which the results found in par. 4 above agree explicitly. The lack of symmetry in the North to South component and the question of veering in par. 7 are specially interesting in connection with his comments on these points.

I might add here that when writing this paper I had not had an opportunity of reading either the paper published in the *Journal* by

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Captain Cave and Mr. J. S. Dines[1] or Part IV. of Sir Napier Shaw's *Manual of Meteorology*.[2]

10. Proceeding to the question of vertical velocities, a number of interesting points arise. The result of plotting the free pull of a number of balloons of equal dead weight, and released from the same point, against their observed velocity over the first ten or fifteen minutes gave a loose mass of points that could not be coaxed on to any curve, but which spread almost evenly on both sides of the curve given by the formula usually spoken of in the field as Dines's, suggesting that, though

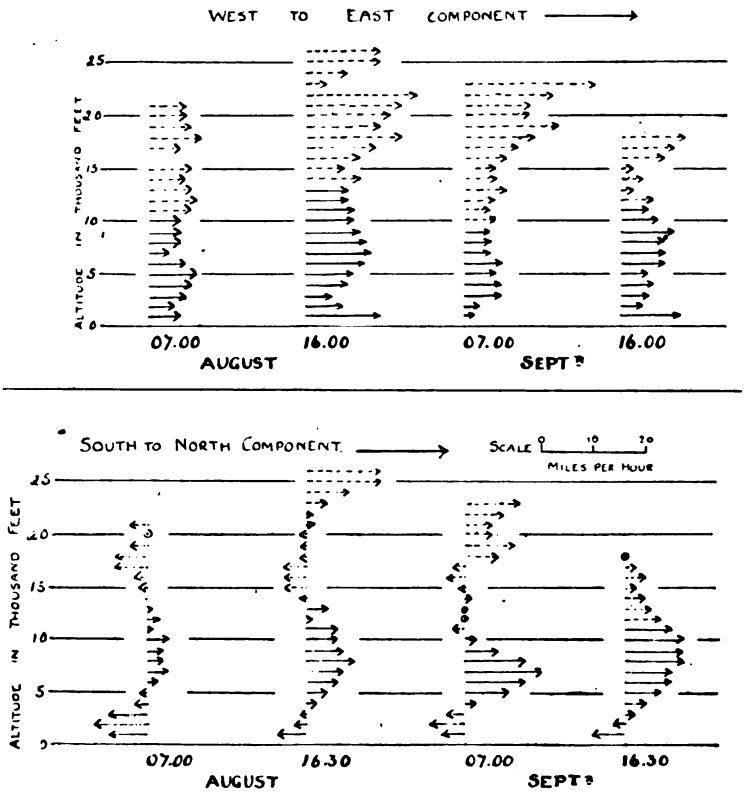

FIG. 8.—Jerusalem. Monthly Averages of Velocity at Various Altitudes.

that formula gave a good arithmetical mean, at the lower levels local eccentricities were liable to introduce big deviations from it in particular cases—differences of 50 per cent being not at all unusual between the actual and theoretical height after ten minutes. The question that arose was whether there was any simple law governing these eccentricities. Attempts were first made to see if they could be correlated with any of the surface meteorological conditions, but without success, and in a short time evidence was forthcoming against the possibility of finding a law, along such lines, of sufficient accuracy to enable the second instrument to be dispensed with altogether, while working in such a country as Palestine.

[1] *Q.J.R. Meteor. Soc.*, **45**, 1919, p. 277. [2] *Cambridge University Press*, 1919.

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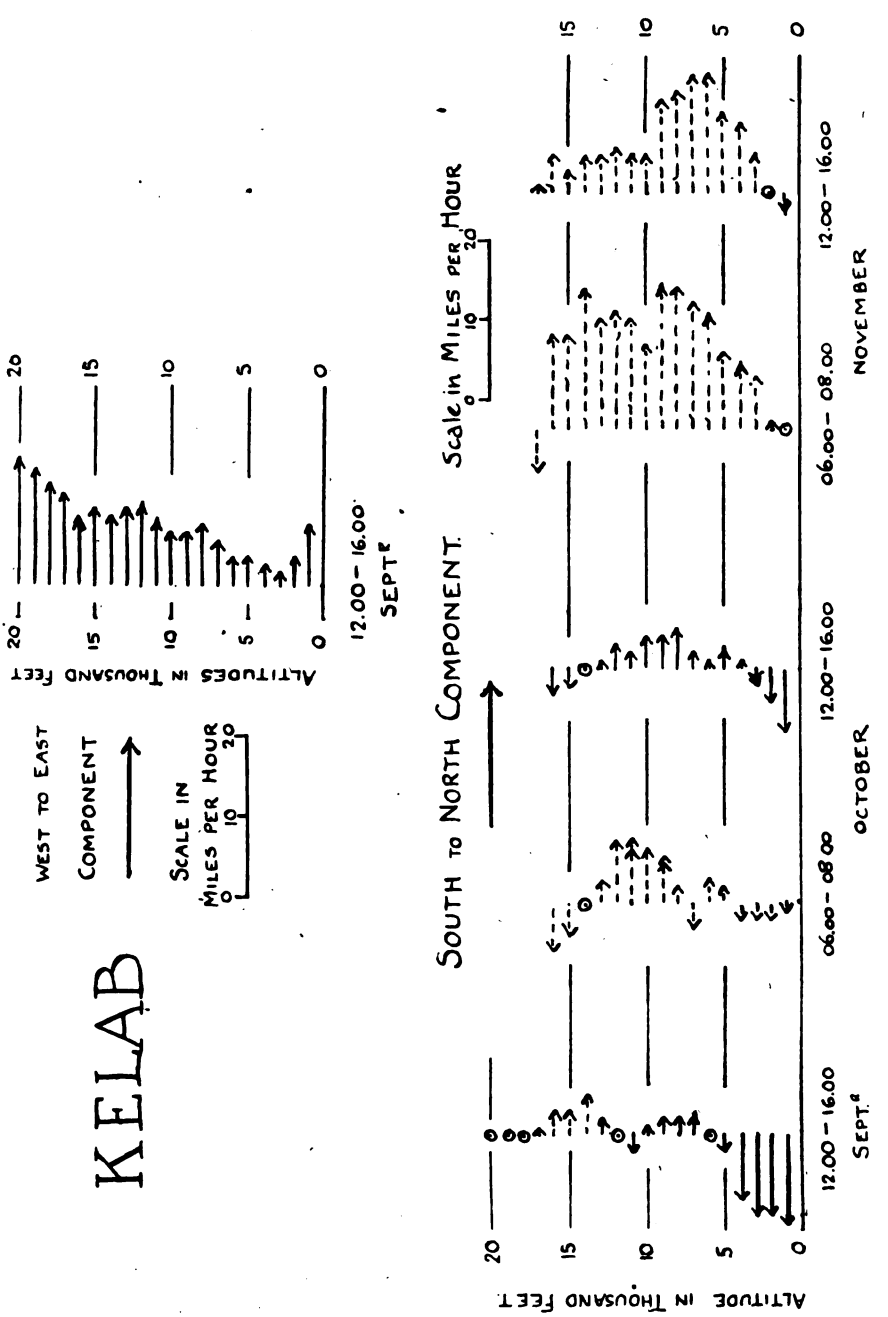

FIG. 4.—Monthly Averages of Velocity at Various Altitudes.

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This evidence consisted in a number of cases, where, owing to the balloon bursting shortly after its release, or getting lost sight of in clouds, or otherwise, a second one was sent up within a few minutes of the first, no appreciable change having occurred during the interval in the surface conditions. In these cases it was often found that the vertical velocities differed considerably, suggesting that the upward

TABLE III.—West to East Component.

Station Jerusalem.

Number of observations and mean velocity in miles per hour.

1918.	August.				September.			
Altitude in thousands of feet.	At 07.00.		At 16.30.		At 07.00.		At 16.30.	
	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	30	+ 6	28	+14	21	+ 2	20	+11
2	30	+ 5	28	+ 7	21	+ 3	20	+ 4
3	30	+ 7	28	+ 5	21	+ 7	20	+ 5
4	28	+ 8	26	+ 8	21	+ 7	18	+ 6
5	26	+ 9	23	+ 9	21	+ 6	17	+ 5
6	23	+ 7	23	+11	21	+ 7	16	+ 8
7	16	+ 4	22	+12	20	+ 5	15	+ 8
8	15	+ 6	19	+11	18	+ 5	15	+ 8
9	12	+ 6	15	+10	12	+ 5	15	+10
10	11	+ 6	14	+ 9	9	+ 6	13	+ 7
11	8	+ 8	12	+ 9	6	+ 5	10	+ 5
12	6	+ 9	10	+ 8	5	+ 6	8	+ 6
13	5	+ 8	10	+ 8	5	+ 8	5	+ 1
14	4	+ 7	6	+10	4	+ 6	5	+ 4
15	4	+ 8	4	+ 7	4	+ 6	4	+ 2
16	...		4	+10	3	+ 8	3	+ 8
17	1	+ 6	4	+13	3	+10	2	+10
18	1	+10	3	+18	2	+13	1	+12
19	1	+ 8	3	+14	2	+18	...	
20	1	+ 7	3	+16	1	+12	...	
21	1	+ 7	2	+18	1	+12	...	
22	...		2	+21	1	+17	...	
23	...		1	+ 4	1	+25	...	
24	...		1	+ 8	...		...	
25	...		1	+14	...		...	
26	...		1	+14	...		...	

or downward currents that affected them were very transient and changeable.

However, while accepting the fact that in the locality in question, and with the balloons and chemicals in use (hydrogen had to be generated on the spot), it was not safe to particularise from averages to an individual ascent, it did seem probable that by taking monthly averages the daily eccentricities would cancel out to a sufficient extent to show some general law.

In Table VII. monthly average vertical velocities at Ramleh are shown for the periods 0-5, 5-10, 10-15, in minutes, corresponding

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roughly to altitudes 0-2000, 2000-4000, 4000-6000 in feet. A slight modification is given in Table VIII., where figures are only included from ascents observed till the 15th minute. This, while reducing the number of observations at the lower layers, ensures that in comparing one layer with another only the same days are dealt with in each case. This information is also shown graphically in Fig. 6, and

TABLE IV.—South to North Component.

Station Jerusalem.

Number of observations and mean velocity in miles per hour.

1918.	August.				September.			
Altitude in thousands of feet.	At 07.00.		At 16.30.		At 07.00.		At 16.30.	
	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	30	− 7	28	− 5	21	− 4	20	− 6
2	30	−10	28	− 2	21	− 6	20	− 2
3	30	− 7	28	− 1	21	− 3	20	+ 2
4	28	− 2	26	+ 2	21	+ 2	18	+ 4
5	26	− 1	23	+ 4	21	+ 8	17	+ 7
6	23	+ 2	23	+ 6	21	+11	16	+ 9
7	16	+ 4	22	+ 7	20	+14	15	+ 9
8	15	+ 3	19	+ 9	18	+11	15	+11
9	12	+ 3	15	+ 7	12	+ 6	15	+11
10	11	+ 4	14	+ 6	9	+ 2	13	+11
11	8	+ 1	12	+ 6	6	− 2	10	+ 9
12	6	+ 2	10	+ 1	5	0	8	+ 6
13	5	+ 1	10	+ 4	5	0	5	+ 5
14	4	0	6	− 1	4	+ 1	5	+ 4
15	4	− 1	4	− 4	4	− 1	4	+ 2
16	4	− 2	4	− 4	3	− 3	3	+ 4
17	1	− 6	4	− 4	3	− 2	2	+ 2
18	1	− 6	3	− 1	2	+ 6	1	0
19	1	− 3	3	− 1	2	+ 9	...	
20	1	0	3	− 1	1	+ 5	...	
21	1	− 3	2	+ 1	1	+ 5	...	
22	...		2	+ 1	1	+ 7	...	
23	...		1	+ 4	1	+10	...	
24	...		1	+ 8	...		...	
25	...		1	+14	...		...	
26	...		1	+14	...		...	

it will be seen that, in every case but one, the mean vertical velocity in the middle layer is slower than in the bottom layer, while in the upper layer it often tends to increase again. This applies equally to Tables VII. and VIII.

It is worth noting here that the point of release of these balloons at Ramleh was on the east slope of a slight rise in undulating country, and some slight assistance may have been given to the vertical velocity at the start by the bending of stream lines over this hill.

Towards the east (which was the commonest initial direction of movement) there was another smaller ridge about 400 yards away, and a

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larger one about a mile away, after which there was a general descent for about a couple of miles to an open plain.

TABLE V.—West to East Component.

Station Kelab.

Number of observations and mean velocity in miles per hour at intervals of 1000 feet. September 1917, between 12.00 and 16.00.

Altitude in 1000 feet.	No.	Velocity.	Altitude in 1000 feet.	No.	Velocity.
		m.p.h.			m.p.h.
1	16	+8	9	14	+ 7
2	16	+4	10	14	+ 7
3	16	+2	11	12	+ 9
4	16	+3	12	11	+11
5	16	+4	13	8	+10
6	16	+4	14	8	+ 9
7	15	+6	15	6	+10
8	14	+8	16	5	+ 9

The average velocity for the first five minutes, is, on the whole, less in Table VIII. than Table VII., *i.e.* the short flights that are cut out from Table VIII. had a high initial velocity. As many of those flights are short, because the balloon was lost sight of in cloud, this is not an unexpected result showing the effect of ascending currents beneath these clouds.

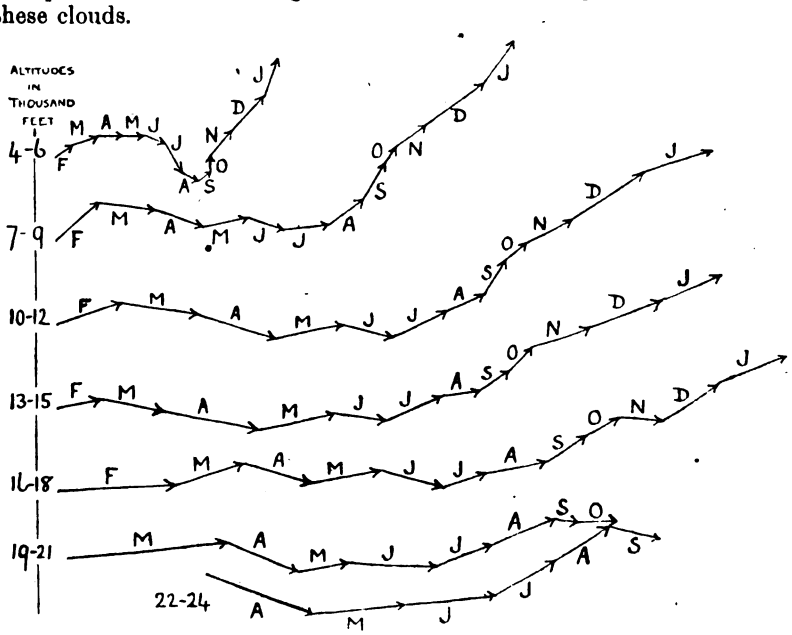

Fig. 5.—Resultant Directions looked at in Plan.

11. Attention is called to the fact that all the above is relative, and that the shape of the curves from Tables VII. and VIII. would hardly be altered at all by adopting a different constant in Dines's formula.

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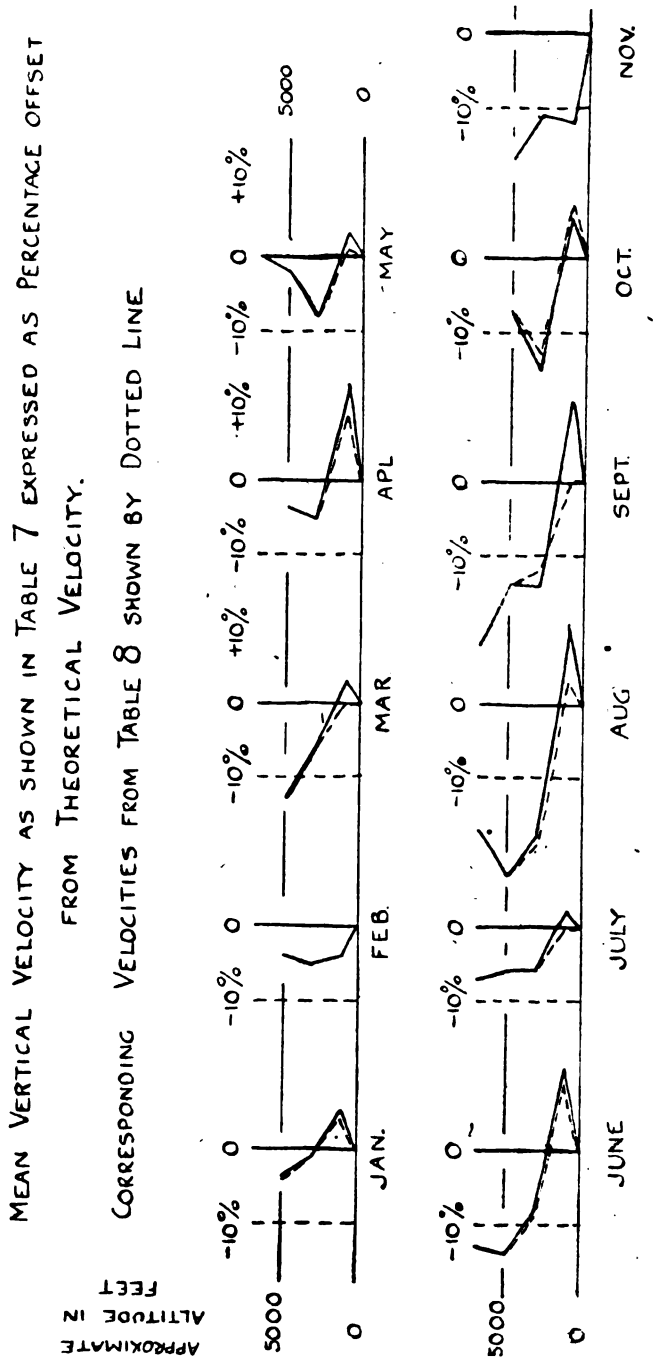

FIG. 6.

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The primary point under discussion is not the best value of the constant in that formula for the average case, but the variability of the component items on each side of what is admittedly a good arithmetical average.

12. This is brought out better in Fig. 7, where flights in 1918 are grouped according to the number of times the velocities in the respective layers differ from the theoretical value by not more than 10, 20, 30 per cent, etc., and the result is given in the form of frequency curves.

In the early part of the summer many of these curves are recognisable as frequency curves, but in March, and from August onwards,

TABLE VI.—South to North Component.

Station Kelab.

Number of observations and mean velocity in miles per hour at intervals of 1000 feet.

1917. Month and Time.	September.		October.				November.			
	12.00-16.00.		06.00-08.00.		12.00-16.00.		06.00-08.00.		12.00-16.00.	
Altitude in 1000 feet.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
		m.p.h.		m.p.h.		m.p.h.		m.p.h.		m.p.h.
1	16	-11	9	-1	30	-8	6	0	9	-3
2	16	-10	9	-2	30	-4	6	+1	9	0
3	16	-10	9	-2	30	-1	6	+7	9	+5
4	16	-8	9	-2	30	+1	6	+9	9	+9
5	16	-2	8	+2	29	+3	6	+10	9	+10
6	16	0	7	+3	25	+1	5	+15	9	+15
7	15	+3	6	-3	23	+2	5	+16	9	+15
8	14	+2	6	+2	22	+5	5	+18	7	+13
9	14	+2	6	+5	18	+4	3	+19	7	+12
10	14	+1	6	+7	16	+4	2	+11	5	+5
11	13	-2	6	+7	15	+2	2	+14	5	+5
12	12	0	6	+8	15	+3	2	+15	4	+6
13	9	+2	5	+3	15	+1	2	+14	4	+5
14	8	+5	5	0	14	0	2	+18	4	+5
15	5	+3	4	-4	11	-2	2	+12	4	+3
16	3	+3	4	-6	10	-3	2	+12	4	+5
17	1	+0	...		...			-5	3	+1

there are some very irregular formations. July is easily the most compact month, although a composite month of Jan. + Feb. is less scattered than might have been expected.

That the 0-15 curves should be more compact than the others may be largely a matter of averages alone, but it is interesting to compare the three layers 0-5, 5-10, 10-15, which, it must be remembered, are quite independent results of direct observation. On the whole there is a clear decrease in dispersion at the higher levels, and in every case but one the lowest layer is the most spread. November is the exception, but the number of observations here is so small that it might well have been combined with October.

Similarly the 10 to 15 layer is generally more compact than the 5-10 one. An exception in October only depends on a few observations, and if there is not much increase in concentration in April and May there is certainly not much expansion.

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August is perhaps the most surprising month in view of the smoothness of the July curves. It certainly shows a decrease in

TABLE VII.—Number of Observations and Averages of Vertical Velocity in the Different Layers of the Ascent expressed as Percentages above or below the Theoretical Velocity.

Period in Minutes.	0-5.		5-10.		10-15.		15-20.		0-15.		0-20.	
Approximate Altitude in 1000 feet.	0-2.		2-4.		4-6.		6-8.		0-6.		0-8.	
Months.	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
January	10	+ 5	9	- 1	9	- 3½	...		0		...	
February	12	- 4	11	- 5	11	- 4	...		- 4		...	
March	28	+ 3	19	- 6	16	- 13	...		- 6		...	
April	24	+ 13	22	- 5	19	- 3½	...		+ 1		...	
May	26	+ 3	26	- 8	25	- 2	18	0	- 2		- 2	
June	24	+ 11	24	- 8	22	- 14	17	- 13	- 4		- 6	
July	28	+ 2	28	- 6	27	- 6	14	- 7	- 3		- 4	
August	38	+ 11	32	- 18	14	- 23	1	- 17	- 10		- 12	
September	31	+ 11	24	- 14	13	- 14	1	- 22	- 6		- 10	
October	27	+ 5	20	- 15	7	- 7	...		- 6		...	
November	17	- 12	8	- 11	2	- 17	...		(- 13)		...	

variation as the balloon ascends, even though its curve for 10-15 is hardly a typical text-book frequency curve.

In this month, and September, frequency curves are shown (dotted) for flights at other times of day and are appreciably smoother than the

TABLE VIII.—Monthly Averages of Vertical Velocity in the Different Layers of the Ascent expressed as Percentages above or below the Theoretical Velocity.

Flights observed for 15 minutes only. Number of observations as in the 10-15 column of Table VII.

Period in Minutes.	0-5.	5-10.	10-15.	0-15.
Approximate Altitude in 1000 feet.	0-2.	2-4.	4-6.	0-6.
	%	%	%	%
January	+ 4	- 1	- 4	0
February	- 4	- 5	- 4	- 4
March	0	- 6	- 13	- 6
April	+ 9	- 5	- 3½	0
May	+ 1	- 8	- 2	- 3
June	+ 9	- 9	- 14	- 5
July	0	- 6	- 6	- 4
August	+ 3	- 19	- 23	- 13
September	0	- 12	- 14	- 9
October	+ 7	- 13	- 7	- 4
November	(- 36)	(- 33)	(- 23)	(- 31)

mid-day ones. As a further point (not shown in the graph), it is interesting that of the early morning flights (8) that contribute to the dotted curve for August there is no point outside the 30 per cent

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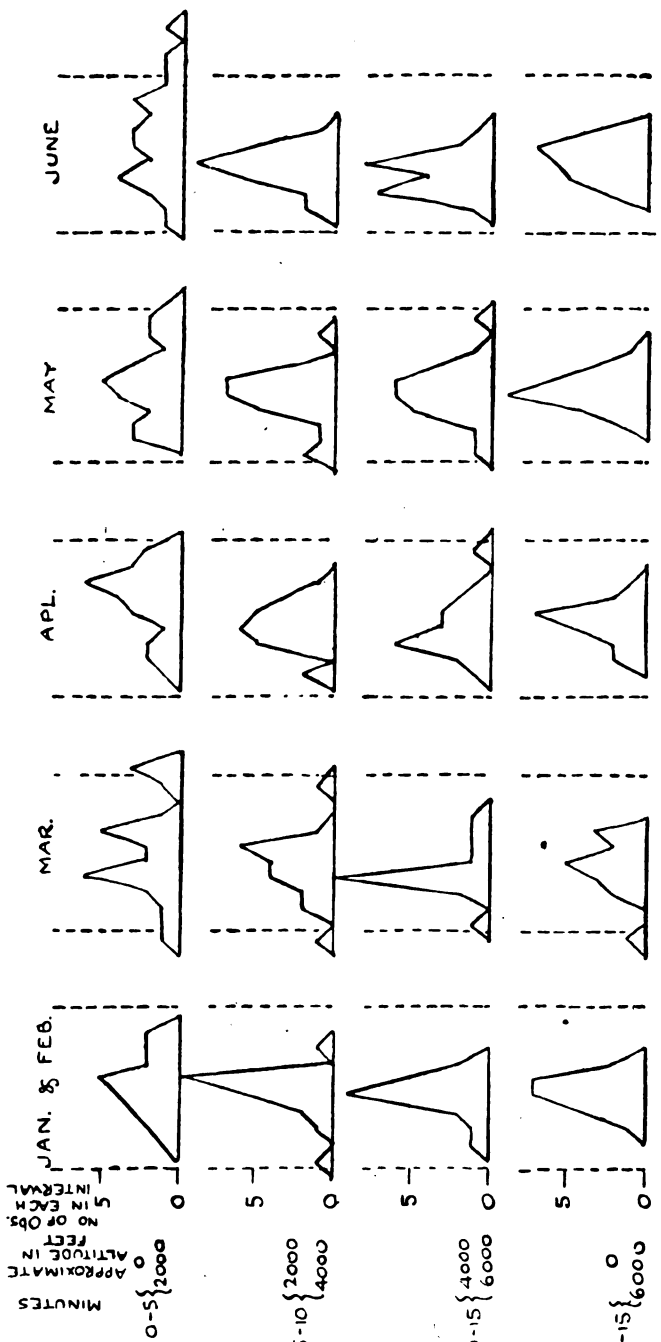

FIG. 7.—Frequency Curves showing Number of Observations in which the Vertical Velocity is included under each of the Successive Groups 0-10%, 10-20%, 20-30% of the Theoretical Velocity. January to June.

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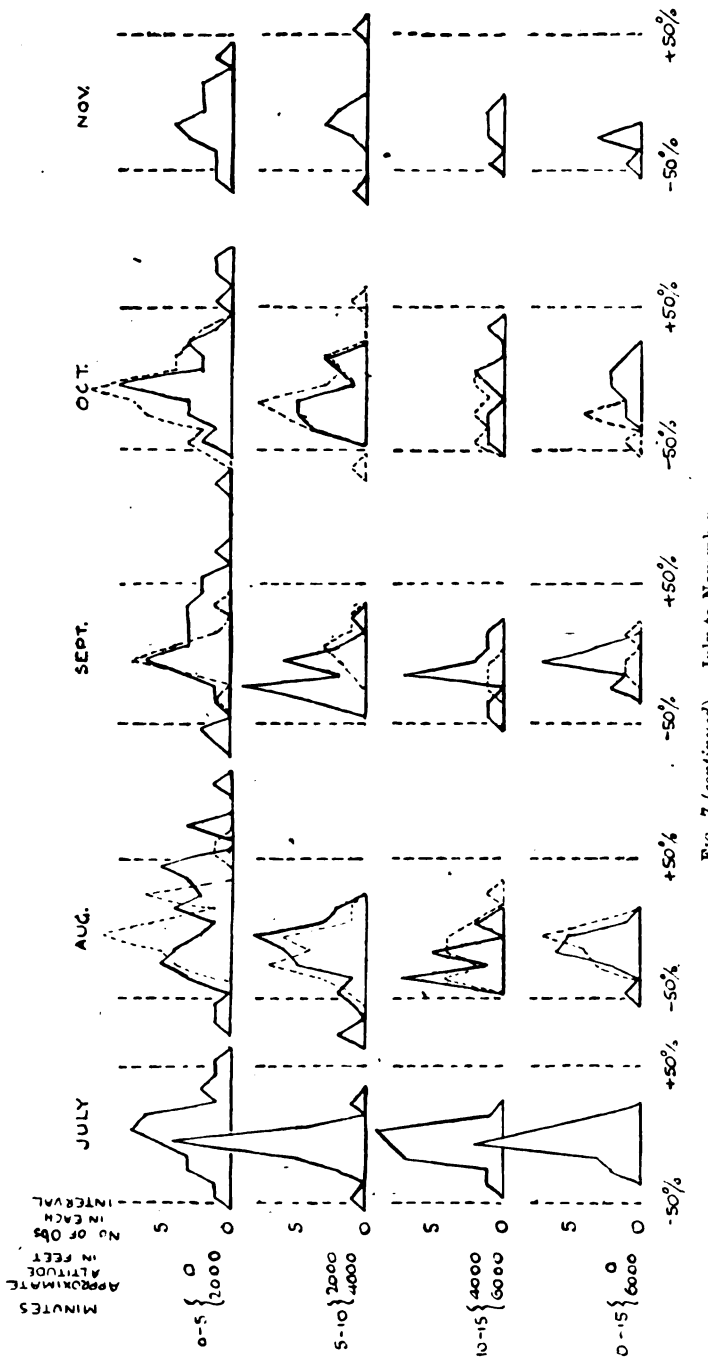

FIG. 7 (*continued*).—July to November.

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variation, whereas in the 0-5 and 10-15 layers mid-day flights have as much outside this limit as inside.

13. Unfortunately I am unable, at the moment, to get the vertical velocity figures from Jerusalem, but speaking from memory I can recall the casual way in which the balloons appeared to hang, as if uncertain whether to go up at all, as they travelled eastward from the Mount of Olives, where they had been released at an altitude of nearly 3000 ft., and passed over ground that fell rapidly toward the Jordan Valley and Dead Sea, and so caused the stream lines to bend down. Here the absolute effect would certainly be largely due to local formation, but it would be interesting to know how it varied from one month to another and from one time of day to another.

14. To summarise such vertical velocity observations as were made at the stations farther west it seems fair to say:

(1) The velocity from 0 to 2000 ft. tended to be above the theoretical value.

(2) The velocity from 2000 to 4000 ft. tended to be below that value and to a greater degree, so that the velocity from 0 to 4000 ft. was on the whole below theory.

(3) The velocity from 4000 to 6000 ft. was slightly slower than from 2000 to 4000 ft.

(4) The variations about the mean were very considerable in the 0 to 2000 ft. layer, but became less pronounced in the succeeding layers.

(5) The frequency curves did not show any marked asymmetry about the numerical mean, *e.g.* it was not a case of a few much in excess being balanced by a large number slightly in defect.

(6) On the whole the compactness in any particular layer was greater in spring and summer than in autumn and winter.

(7) In the few months when enough observations were made to discuss the point, the mid-day observations were appreciably more dispersed than those in the early morning or evening.

15. In conclusion I should like to mention that in bringing together these figures I am collecting the work of a number of other observers who, besides myself, were engaged in this work at different times and in the various places named: notably, Capts. P. A. Curry and P. S. Barlow, Lt. W. Thomas and 2/Lt. A. E. Evans.

DISCUSSION.

Mr. J. S. DINES said that the Society should be grateful to Capt. Bamford for his paper, as the data presented referred to a locality in which, so far as he knew, upper air observations had not been made in the past. Another valuable feature of the work lay in the use of two theodolites, or one theodolite and a range-finder, so that definite results could be obtained without the uncertainties inherent in the single theodolite method. He quite agreed with Capt. Bamford's conclusion that it was not possible to correlate the rate of ascent with any meteorological condition. He had found that two balloons sent up one immediately after the other often went up with widely different rates of ascent. He would like to ask what was the size of the balloons used, because there was a certain amount of evidence to show that quite large

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balloons went up faster than the formula would suggest. It was satisfactory to see that the formula was in agreement with the results obtained in Palestine.

Mr. F. J. W. WHIPPLE thought it was very remarkable that the frequency curves should be so symmetrical. It would not have been expected that the lifting effect of rising currents of air would be balanced exactly by the retarding effect of falling currents, but the curves seemed to indicate that this was the case. Mr. J. S. Dines had called attention to the regularity with which the north component of the wind was replaced by a south component at about 10,000 ft. It was perhaps more remarkable that the south component after reaching a certain strength fell off again at greater heights.

Capt. W. H. PICK asked Capt. Bamford if he had found that the velocity increased irregularly with the height and whether any general rule as to how the behaviour at 3000 feet could be got from the behaviour at 1000 feet. Many attempts had been made in France to obtain this, but the results had not been satisfactory. He would also like to ask Capt. Bamford if he had had any high ascents, say over 20,000 feet, and if so whether the wind up there was Westerly. In Russia it had been found to be always between NW and SW at very high altitudes. It would be interesting if the surface temperatures could be obtained for various stations at good distances apart and under equal conditions of cloud amount to see if the surface temperature gradient made any difference to the upward velocity.

Lieut. J. S. TURNER asked what type of range-finder was used and whether the readings were the altitude of the pilot balloon or the distance with the angle of elevation.

Capt. A. J. BAMFORD said in reply to Mr. Dines that at first the balloons were of a dead weight of 15 grams and came from some French source, and later were larger and came from the Meteorological Office. In reply to Capt. Pick, he said he had not seen any direct evidence in Palestine of an increase of velocity proportional to altitude. In reply to Lieut. Turner he said that the range-finder was a Barr and Stroud pattern and gave the absolute distance of the balloon. Altitude and horizontal distance were read from two graphs, in each of which vertical angle was plotted against range.

A New Formula for the Rate of Ascent of Balloons.

The issue of the U.S. *Monthly Weather Review* for April 1919 contains a paper of considerable interest in which the war-time activities of the Weather Bureau and of the Meteorological Section of the U.S.A. Signal Corps are dealt with in some detail. The part of the paper to which it is desired to direct attention in the present notice is that which discusses the pilot balloon work of the Signal Corps and more particularly the rate of ascent of balloons. The formula for rate of ascent.

$$V = q \cdot \frac{L^{\frac{1}{2}}}{(W+L)^{\frac{1}{4}}}, \quad (L = \text{free lift, } W = \text{dead weight}) \quad . \quad . \quad \text{I.}$$

in use in this country was tried, and also the well-known formula due to Hergesell, but neither of these was found to be satisfactory over the range of balloons employed. The following new formula was then worked out empirically:

$$V = 71 \cdot \left\{ \frac{L}{(W+L)^{\frac{1}{4}}} \right\}^{\frac{5}{8}} \quad . \quad . \quad . \quad . \quad . \quad \text{II.}$$

It will be seen that this differs from the British formula I. in the index to which the expression in the bracket is raised, $\frac{5}{8}$ being substituted for $\frac{1}{2}$. The value of the constant is also adjusted, 71 being used in place of the 84 generally adopted in the British formula. The chief interest of this new formula lies in

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the fact that it is based upon a very considerable series of double-theodolite ascents; 5000 ascents were available from which 1000 were selected on account of their length and accuracy. The formula is thus reared on a very firm practical foundation. Unfortunately in the article under notice few details are given, and the publication of such will be awaited with interest. It is useful to compare the formulæ I. and II. for balloons of different weights and free lifts. This is done in the following table.

RATE OF ASCENT V IN METRES PER MINUTE.

$V = 71\left\{\frac{L}{(W+L)^{\frac{1}{3}}}\right\}^{\frac{1}{2}}$—ordinary type. $V = 84 . \frac{L^{\frac{1}{2}}}{(W+L)^{\frac{1}{3}}}$—italic type.

W	L = 25	50	100	200	300 g.
10 g.	*128*	*152*	*175*	*200*	*216*
	121	149	177	209	230
20	*118*	*144*	*170*	*197*	*213*
	109	139	172	205	227
30	*110*	*138*	*166*	*194*	*211*
	100	132	166	202	224
40	*104*	*133*	*162*	*191*	*209*
	93	125	161	198	221
50	*100*	*128*	*158*	*188*	*207*
	88	120	156	194	218

It will be noticed that the U.S.A. formula (II.) gives smaller rates of ascent than the British formula (I.) for balloons of small free lift and larger for balloons of large lift, thus making the range of velocity greater. With a free lift of 100 g. the difference between the two formulæ is not very material, whether the balloon is large or small. If a small balloon is used to give a low rate of ascent (W = 10, L = 25) the difference amounts to 7 m/min., that is between 5 and 6 per cent on the rising velocity, the British value being in excess. If a large balloon is employed, giving a high rate of ascent (W = 50, L = 300), the difference amounts to 11 m/min., or about 5 per cent, the British value being in this case the smaller. These examples show the nature of the differences met with. Experiments made in this country have yielded some evidence that the value q = 84 in formula (I.) gives too large a value for the rising velocity of small balloons, though it is satisfactory for the types commonly employed.[1] The new formula would appear to correct the above fault.

One of the most comprehensive papers on the rate of ascent of pilot balloons that has appeared is that of Hesselberg and Birkeland, an abstract of which was published in the *Quarterly Journal* for April 1918 (p. 131). The formula adopted by these authors was of type (I.), but it was found that at a certain free lift somewhat of a "discontinuity" occurred; above this, balloons went up more quickly than would be anticipated from the behaviour of smaller balloons. The U.S.A. formula does not provide any such break, and it would be interesting to learn whether the Officers of the Signal Corps failed to find any such discontinuity or considered that a formula which bridged the gap and gave approximately correct results on either side of it was of sufficient accuracy for practical use. It would appear that the 5000 double-theodolite ascents now available would provide excellent material for testing the accuracy of Hesselberg's conclusions. The new formula certainly merits close attention on the part of those engaged in pilot balloon work.

J. S. DINES.

November 1919.

[1] *Q. J. R. Meteor. Soc.*, **45**, 1919, p. 282.

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BAROMETRIC PRESSURE AND UNDERGROUND WATER-LEVEL.

By E. G. BILHAM, B.Sc., F.R.Met.Soc.

[Received May 29—Read November 19, 1919.]

THE fact that the water-level in a well may be sensitive to changes of barometric pressure has been known for many years. The late Mr. Baldwin Latham[1] showed, as long ago as 1881, that a decrease of pressure facilitated percolation, increased the discharge of water from springs and caused a rise of subsoil water-level. In 1883 the variations of level in a well at Maghull, near Liverpool, were continuously recorded by Mr. (afterwards Dr.) Isaac Roberts by means of apparatus which appears to have been similar in all essential respects to that now in use at Kew Observatory, Richmond. The comparison of the water-level traces with barograms during periods of noteworthy barometric variation left no shadow of doubt that the water surface was very sensitive to pressure changes. Solar and lunar semi-diurnal tides were also detected in the well.

It is a matter of some interest to compare the results obtained by Roberts with those recently obtained at Kew Observatory. It should be noticed at the outset, however, that the experimental conditions differ considerably. At Maghull an artesian well was bored through the triassic rocks to below sea-level, so that the rise and fall of a column of water 60 ft. high was available for study. The station was 8 miles to north-east of Liverpool, and apparently in no close contiguity to any large body of tidal water. At Kew Observatory, on the other hand, the well is shallow (only 11 ft. from the Observatory basement to the bottom of the well) and the soil consists of sand and gravel resting on London clay. The strongly tidal river Thames is only 300 yards to westward.

Under these circumstances it seems more remarkable that solar and lunar tidal effects could be detected at Maghull than at Kew. Chief interest, however, attaches to the effects of barometric pressure. Simultaneous traces from a barograph and the water-level recorder at Maghull are reproduced in *Symons's Meteorological Magazine*, 1883, page 134, and 1884, page 5. The first relates to the passage of a depression between March 21 and April 1, 1883, from which it appears that a fall of pressure of one mercury-inch was associated with a rise of water of 2·75 in., or, reverting to the units employed in the discussion of the Kew results,[2] the sensitiveness was equal to 2·1 mm./mb. In the second case the effect of the barometric disturbances between December 10 and 16, 1883, is illustrated, and in this instance, omitting the earlier portion of the curves in which the agreement is least satisfactory, a fall of one mercury-inch of pressure was associated with a rise of 4·85 in. in the water-level, giving a value of 3·6 mm./mb. for the sensitiveness. It would appear therefore that at Maghull the response of the water-level to changes of pressure may vary considerably.

[1] *London, Rep. Brit. Ass.*, 1881, p. 614; see also 1883, p. 495.
[2] *London, Proc. R. Soc.*, **94** (Ser. A), 1917, p. 168.

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At Kew it was found that the sensitiveness varied according to the height of the water in the well, high levels being associated with high sensitiveness. The average value of the factor fluctuates between 0·5 for levels below 2 metres above Ordnance Datum to 4·0 or more when the level reaches 4 metres above M.S.L., above which point the sensitiveness increases very rapidly. Thus the Maghull values are within the range of variation found to occur at Kew. From the diagrams appended to Roberts' papers it would appear that the water-level at Maghull was slightly higher in December 1883 than in March and April of that year; but the difference is one of a few inches only. In reply to an inquiry about the variation of subsoil water-level in the neighbourhood of Liverpool during this period, Mr. Joseph Baxendell of Southport, to whom I am indebted for bringing Dr. Roberts' work to my notice, writes:

I have come to the conclusion that the sensitiveness of the wells does not really depend on the absolute height of the water, though when averages are taken from a fair collection of observations, the two will always go together. But that which actually matters appears to be the extent to which the ground above the water-line (*i.e.* from the surface of the land downwards) is wetted. When this soil or rock is drier than usual, the sensitiveness of the well is reduced, even though the water may be high, as occasionally happens. But when once the ground has become well soaked, one finds increased sensitivity even though the water be still low. If my memory serves me, Mr. Baldwin Latham came to a somewhat similar conclusion.

Now the water was higher in December 1883 than in March–April of the same year both here (at Birkdale) and at Maghull, but not much, and indeed in Isaac Roberts' own well only a couple of inches or so. These few inches between the two occasions cannot explain the considerable difference in the sensitivity. But from our own well and rainfall records (at Birkdale and Hesketh Park) I find that there was a great difference between the wetness of the ground in March and December 1883. In January 1883 the water in the wells was higher than it has ever been since—certainly until this present week! (To-day [March 20, 1919] the flooding is approximating to that of thirty-six years ago.) Relatively to that very abnormal height of January 1883, the level in March–April, which looks high, was quite low. For, after January, the rainfall steadily diminished, the water in the wells fell rapidly, and by March–April the ground must have been really pretty dry—as dry as it usually is when the water is considerably lower. The Southport rainfalls for the three months were:

1883, February = 2·12 in.; March = 1·28 in.; April = 0·69 in.

In the December case conditions were completely reversed. September had brought 3·95 in., October 4·62 in. and November 4·10 in., so that by December the ground must have been almost saturated, and one would expect great sensitiveness. Moreover, humidity was unusually low in March, and remarkably high in November and December.

I venture to think that, in Lancashire, it is really the condition of the soil, rather than the absolute height of the water, that determines sensitiveness to pressure changes. Of course, in general (as I have said), the two go together.

I had myself[1] expressed the opinion that the condition of the soil rather than the absolute level was the factor which determined the sensitiveness. In any case the variability in sensitiveness, which does

[1] *Loc. cit.* p. 172.

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not appear to be associated with sluggishness or lag when the water is low, must be regarded as a characteristic feature of both the Kew and Maghull wells.

Mr. Baxendell further informs me that small but indubitable changes of level occur in surface wells at Southport and Birkdale in response to large changes of pressure. These wells are sunk entirely in blown sea-sand and are very shallow, the water-level never falling below 5 ft. from the surface, and sometimes rising to within a foot or two of it.

ADDENDUM.

[Received July 5, 1919.]

A VALUABLE contribution to the literature of the subject was made by Prof. K. Honda[1] in 1904 in a paper which gives results from a number of artesian wells situated at distances varying from 2 k. to 6 k. from Tokyo Bay. In only two of the wells could a response to slow changes of barometric pressure be detected. These wells were situated at Tokyo and Yokohama, and were respectively 380 m. and 300 m. deep. The value of the sensitiveness in the Tokyo well was 3·3 mm./mb., and in the Yokohama well 2·7 mm./mb. In a well at Yoshiwara, 24 m. deep, no effect due to slow-pressure changes was observed, but short-period oscillations attributed to the rapid fluctuations of atmospheric pressure which accompany wind could be detected. These were also seen at Tokyo and Yokohama, and are well marked in the Kew records.

All the artesian wells responded to the tidal movements in Tokyo Bay, and except in one instance the phases of the movements of water-level in the wells were in exact agreement with those in the Bay.

A surface well 10 m. deep at Tokyo was found to be very sensitive to rainfall, but was not affected in the slightest degree by barometric pressure or tidal movements. As this well is the only one of the five examined by Honda whose depth is at all comparable with that of the Kew well, it is remarkable that their behaviour should differ so markedly.

Prof. Honda's explanation of the phenomenon agrees with that suggested by the present author in so far as the level change in the well is ascribed to a difference between the pressure operating on the free water-surface, and that operating on the subsoil water. He points out, moreover, that the determination of the relation between changes of pressure and water-level furnishes data from which the reduction in amplitude of the pressure changes experienced at a known depth below the surface can be obtained. Thus if the height of water in a well of depth D is u mm. when the atmospheric pressure is p, measured in mm. of water, the pressure at the bottom of the well is $p + u$, and is necessarily the same at the same level outside the well if the water is in equilibrium. If an increase of pressure δp is accompanied by a fall of level δu the new pressure at the bottom of the well is $p + u + \delta p - \delta u$. Consequently the change of pressure δp_D at a depth D which accompanies a change δp at the surface is equal to $\delta p - \delta u$ and $\frac{\delta p_D}{\delta p} = 1 - \frac{\delta u}{\delta p}$.

[1] "Daily Periodic Change of the Level in Artesian Wells." Pubn. of the Earthquake Investigation Committee in Foreign Languages, Tokyo, 1904, p. 73.

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If δp is measured in millibars, we have $\frac{\delta p_D}{\delta p} = 1 - 0{\cdot}1002\frac{\delta u}{\delta p}$. Prof. Honda considers that it is highly desirable to determine the "reduction-factor" $\frac{\delta p_D}{\delta p}$ at various depths in different parts of the world. The information obtained in this way should be of interest to seismologists. At Kew at a depth of 11 ft. it varies from 0·6 to 0·94, according to the condition of the soil. At Tokyo its value is unity at a depth of 10 m. and 0·68 at 380 m.

It must be observed that if there is any direct correlation between the height of water in a well and the sensitiveness, the matter is not so simple as the above calculation would imply, since $\frac{\delta u}{\delta p}$ is then a function of p_D. The question could only be settled by eliminating the effects of variations in the condition of the soil, and that would hardly appear to be possible.

Drought in Ceará, Brazil, in 1919.

Through the assistance of Mr. Herbert J. Evans, of Fortaleza, the rainfall data, in continuation of the values to 1915 already published,[1] have been supplied by Professor Francisco Dias Da Rocha, Director of the "Museu Rocha." The returns, which refer to the period January 1916 to September 1919, are of considerable interest. They show that after three successive wet seasons, during which the rainfall from January to June (the rainy season) was respectively 24 per cent, 45 per cent, and 28 per cent above the 70 years' average, 1849-1918, the pendulum has swung the other way, since in the first 6 months of the present year only 388 mm. of rain fell, or 31 per cent of the average. The only years back to 1849 with a smaller rainfall for the rainy season were those of 1877, when 350 mm. fell, and 1900, when only 267 mm. was measured. March 1919 was the driest on record, with only 29 mm., the previous smallest March rainfall being 42 mm. in 1900. As the first three months of the dry season were relatively wet, the monthly totals for the first nine months of the present year show a small amplitude, the amounts recorded varying from 28 mm. in September to 140 mm. in April. The additional values kindly supplied by Prof. Rocha are as follows, the mean monthly and annual fall for the 70 years, 1849–1918, being appended for comparison.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
1916 .	131	94	351	532	291	175	1	1	18	6	7	116	1723
1917 .	464	267	313	183	455	162	5	14	10	0	65	24	1962
1918 .	141	196	460	226	491	116	24	19	51	1	16	71	1812
1919 .	41	63	29	140	70	45	59	35	28	...	...	...	...
Mean 1849–1918	87	179	301	340	245	121	53	28	16	13	14	39	1436

The total number of days with rain during the first six months of the present year was 51, against 35 in the corresponding period of 1878, and 42 in 1900, but the comparison is open to doubt, as days with 0·1 mm. are probably included in the present instance, instead of being left out.

R. C. Mossman.

November 10, 1919.

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[1] *London, Q. J. R. Meteor. Soc.*, **45**, 1919, pp. 69-79.

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THE LAWS OF APPROACH TO THE GEOSTROPHIC WIND.

By F. J. W. WHIPPLE, M.A., F.R.Met.Soc.

[Received May 21—Read December 17, 1919.]

INVESTIGATIONS theoretical and practical concerning the way in which wind varies with height occupy an important position in recent meteorological literature. In this country the work of G. I. Taylor[1] is regarded as of the first importance, but in this field he was anticipated to a certain extent by Filip Åkerblom,[2] who set out the correct principles in his discussion of the Eiffel Tower observations. The theory has also been extended by T. Hesselberg and H. U. Sverdrup,[3] in whose treatment of the subject some of the results set out below have been published. My attention was not called to the work of these authors until after the present paper had been written. Moreover, the difference in the way of approaching the subject may justify a certain amount of repetition.

In the following pages a geometrical form is given not only to the results in question but also to the argument by which they are reached. It is hoped that this will make them of more general service to meteorologists. The "laws" which are enunciated are only valid under ideal simplified conditions, but in the latter part of the paper the analysis has been extended to allow for uniform variation in the barometric gradient with height.

2. The winds which are shown on the ordinary weather map are the winds observed at the earth's surface, and as a general rule they are inclined at a small angle to the isobars, blowing inwards from the high pressure to the low pressure. It is also a general rule that the strength of the wind is proportional to the closeness of the isobars, *i.e.* to the pressure gradient. Observations show that at a few hundred metres from the ground the wind blows very nearly along the isobars, and the strength is to an equally good approximation proportional to the pressure gradient; in fact, at such a height the actual wind is approximately equal to the "Gradient Wind," computed from the pressure distribution at sea-level.

The gradient wind may be defined as a hypothetical wind blowing along the isobars with such speed that the prevailing pressures would balance the deviating tendency of the earth and also centrifugal action. The gradient wind speed V is determined by the equation

$$\gamma/\rho = 2\omega V \sin\lambda + V^2/r, \quad . \quad . \quad . \quad . \quad 2{\cdot}1$$

where γ is the pressure-gradient, ρ the density of the air, ω the angular velocity of the earth, λ the latitude of the place of observation, and r the radius of curvature (to the left in the northern hemisphere) of the

[1] "On Eddy-Motion in the Atmosphere," *London, Phil. Trans. R. Soc.*, **215** (Ser. A), 1915, p. 1; and "Phenomena connected with Turbulence in the Lower Atmosphere," *London, Proc. R. Soc.*, **94** (Ser. A.), 1918, p. 137.

[2] "Recherches sur les courants les plus bas de l'Atmosphère au-dessus de Paris," *Upsala, Soc. Scient. Acta*, **2** (Ser. 4), 1908, No. 2.

[3] Hesselberg und Sverdrup. "Die Windänderung mit der Höhe vom Erdboden bis etwa 3000 m. Höhe," *Beitr. Physik Atmosph., Leipzig*, **7**, 1916, p. 156.

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path of the wind. As the isobars are not stationary the wind-tracks do not in general coincide with the isobars drawn for any particular instant, and it is not easy to frame an entirely satisfactory hypothesis by which to determine r. Accordingly the last term in equation 2·1 is usually ignored.

Sir Napier Shaw has recently introduced the name "Geostrophic Wind" for the wind computed from the simplified equation

$$\gamma/\rho = 2\omega V \sin\lambda. \quad . \quad . \quad . \quad . \quad 2{\cdot}2$$

In what follows we shall not be considering the curvature of the wind-tracks, so the distinction between gradient wind and geostrophic wind will be immaterial.

The geostrophic wind represents the main stream of air, whereas the surface wind is this main stream affected by the friction at the earth's surface. It is proposed to regard the geostrophic wind as fundamental, and to think of the actual wind at any height as compounded of the geostrophic wind and a "relative wind" for that level.

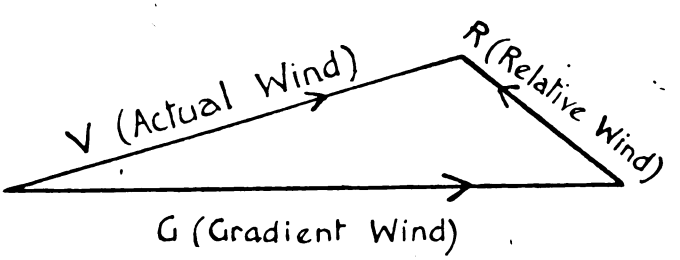

FIG. 1.

The relative wind is defined as wind with such a velocity that when it is compounded vectorially with the geostrophic wind velocity the resultant is the actual velocity. As we go up from the surface the actual wind gets nearer to the geostrophic wind, and therefore the relative wind falls off.

3. Making use of these ideas we propose to consider a system for which the following laws hold:

I. The relative wind falls off with increase of height according to the exponential law

$$R = R_0 e^{-B(z-z_0)}, \quad . \quad . \quad . \quad . \quad 3{\cdot}1$$

when R is the relative wind at the height z, R_0 the relative wind at the height z_0, and B is a constant.

II. The direction of the relative wind turns uniformly with increase of height, the circular measure, ϕ, of its azimuth being given by

$$\phi - \phi_0 = B(z - z_0), \quad . \quad . \quad . \quad . \quad 3{\cdot}2$$

where B is the same constant as before.

III. The angle between the actual wind near the earth's surface and the relative wind there is 135°. The exact significance of the phrase "near the surface" will be discussed in the sequel.

If $B(z - z_0)$ is eliminated from the equations in the first two of these "laws" it is seen that

$$R = R_0 e^{-(\phi - \phi_0)}. \quad . \quad . \quad . \quad . \quad 3{\cdot}3$$

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Accordingly, if the relative winds at all heights are represented by straight lines CP drawn from a fixed origin C, the extremities of these straight lines lie on an equiangular spiral. The constant angle between the radius vector and the tangent to this spiral is 45°. Moreover, the third law indicates that the straight line OP representing the actual wind "near the surface" is a tangent to the spiral.

Before discussing the foundation of the theory we may notice the significance of certain points on the diagram [1] (Fig. 2).

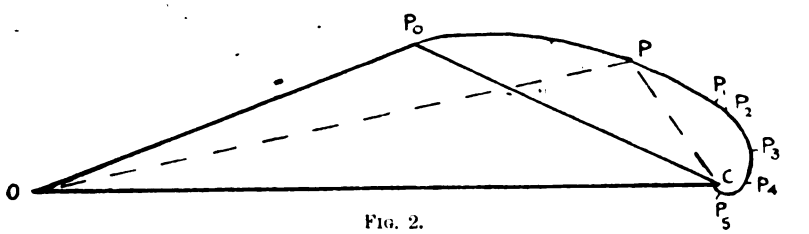

FIG. 2.

The wind "near the surface" is represented by the line OP_0 and the angle OP_0C is 135°. As we go up the wind increases, but the change in direction is not appreciable at first. The actual wind is equal in magnitude to the gradient wind at the height which corresponds with the point P_1. At this height the deviation from the gradient direction is considerable. The wind goes on increasing beyond the gradient wind and reaches its maximum at P_3. At a slightly greater height (P_4) the gradient wind direction is reached, *i.e.* the wind blows along the isobars. At the height corresponding with P_5 the gradient speed is reached for the second time. The actual gradient velocity correct in strength and direction is approached continually, but in the idealised theory it is never reached.

The following table has been drawn up for the special case when the surface wind is inclined at 20° to the gradient wind and the rotation of the relative wind is one degree in 6 metres. The gradient wind is taken as 10 m/s. These data are chosen so as to correspond with some of G. M. B. Dobson's Salisbury Plain observations.[2]

Height above Ground in Metres.	Representative Point Fig. 2.	Relative Wind.		Actual Wind.	
		Inclination to Gradient Wind $\phi+25°$.	Speed R m/s.	Inclination to Gradient Wind.	Speed m/s.
		°		° ′	
0	P_0	25	4·84	20 0	6·0
30	...	30	4·43	19 50	6·6
60	...	35	4·06	19 0	7·1
90	...	40	3·73	18 33	7·4
360	P_1	85	1·70	9 40	10·0
390	P_2	90	1·56	8 55	10·2
660	P_3	135	0·71	2 45	10·5
930	P_4	180	0·32	...	10·3
1470	P_5	270	0·07	−0 30	10·0
2010	...	360	0·014	...	9·986

[1] Cf. Hesselberg u. Sverdrup, *l.c.* p. 159.

[2] *Q. J. R. Meteor. Soc.*, **40**, 1914, p. 123. For moderate winds at the "surface" Dobson gives V/G = ·65. Inclination of V to G 21½°. The gradient-speed is reached at 300 m., the gradient direction at 1000 m. *Cf. Manual of Meteorology*, Part IV., 1919, p. 37.

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With more vigorous eddy motion the vertical scale would be increased and the geostrophic wind would be approached more slowly. With more surface friction OP_0 would be smaller in comparison with OC.

4. *Theoretical Basis of Laws I. and II.*—The theoretical justification of the Laws of Approach to the Geostrophic Wind depends on the following assumptions. It will be noticed that the assumptions are not likely to be strictly valid on any particular occasion.

(1) The variations in the density of the air in the range of height considered may be neglected.

(2) The isobars at all heights considered are sensibly straight and parallel and without motion, and the gradient is the same at all heights.

(3) There are no steady vertical currents.

(4) The rate at which air is transferred from layer to layer by eddies is the same at all heights.

Consider the air at any level. It is influenced by the general distribution of pressure so that it has a tendency to move from places where pressure is high to places where it is low. The admixture of air brought down to a specified level by eddies increases the average speed, and on the other hand the mixture of air from below decreases the average speed. Moreover, owing to the rotation of the earth, the direction of motion tends to turn to the right. As the general flow is supposed to be steady at all levels, these tendencies must just balance one another. We proceed to put the relation between them in algebraic form.

In accordance with definition, the acceleration produced by the pressure gradient is $2\omega \sin \lambda \,.\, G$, where ω is the angular velocity of the earth, λ the latitude, and G the speed of the geostrophic wind. The apparent acceleration produced by the earth's rotation is $2\omega \sin \lambda \,.\, V$, where V is the actual velocity of the wind. The resultant of these two accelerations $2\omega \sin \lambda \,.\, G$ and $2\omega \sin \lambda \,.\, V$ is $2\omega \sin \lambda \,.\, R$ at right angles to the "relative velocity," R.

Now consider the exchange of momentum between one layer of air and that above it. Let OP represent the velocity of the lower layer,

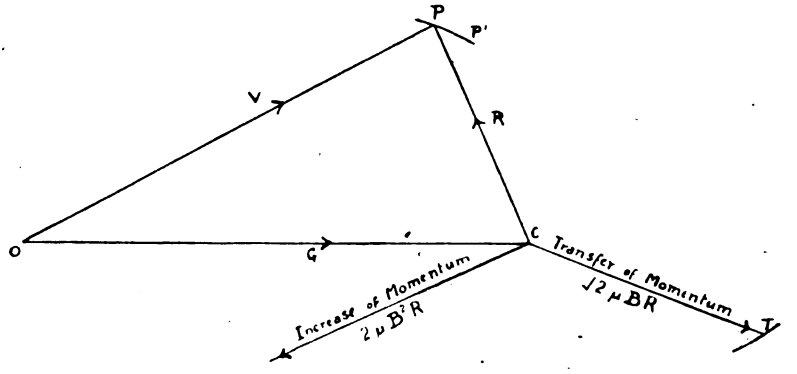

FIG. 3.

OP′ the velocity of the upper layer. The air lost by the lower layer has momentum in the direction OP; the air gained has momentum in the direction OP′, and since equal masses of air ascend and descend the net gain of momentum is in the direction PP′. This line PP′ is a

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chord of the velocity spiral; when the layers are comparatively shallow PP′ may be regarded as the tangent of the spiral. Thus the rate at which momentum is brought into a layer from above can be represented by a straight line CT parallel to the tangent at P. According to the theory the spiral is equiangular, the angle between CT and CP being a constant 135°.

Suppose that the air brought down across a horizontal surface at height z comes on the average from the height $z + \frac{1}{2}h$, where the horizontal velocity is V_1, and that the air carried upwards comes from the level $z - \frac{1}{2}h$, where the horizontal velocity is V_2, that the average velocity of descent or ascent is u, and that the density is ρ. The air is descending over half the total area so that on the average the rate at which momentum is transferred downwards across unit area is $\frac{1}{2}u\rho V_1$. Similarly, the rate of transfer upwards is $\frac{1}{2}u\rho V_2$, and hence the excess rate downwards is $\frac{1}{2}u\rho(V_1 - V_2)$. This is approximately[1] equal to $\frac{1}{2}u\rho h\frac{\delta V}{\delta z}$. Taylor denotes $\frac{1}{2}u\rho h$, which he calls the eddy viscosity, by the letter μ, so that the rate of transfer of momentum downwards may be written $\mu\frac{\delta V}{\delta z}$.

As V in this formula is a vector, $\frac{\delta V}{\delta z}$ is also a vector: $\frac{\delta V}{\delta z}$ is in the direction of CT and of magnitude $\sqrt{2}R\frac{\delta\phi}{\delta z}$, *i.e.* in accordance with the relation 3·2, of magnitude $\sqrt{2}BR$. It follows that the rate of transfer of momentum downwards is $\sqrt{2}\mu BR$.

Now consider the difference between the net flow of momentum into a layer from above and the net flow out of it below. If the thickness is dz, the difference is $\sqrt{2}\mu B\frac{\delta R}{\delta z}dz$, which by Law I. is $2\mu B^2 R dz$, and this is a vector making 45° with CT and, therefore, at right angles to CP.

Thus the additional momentum gained in unit time by unit volume of air on account of the eddies is $2B^2\mu R$ at right angles to CP, and since the net effect of the pressure and the earth's rotation was shown to be an acceleration $2\omega \sin\lambda . R$ also at right angles to CP, these changes of momentum are equal and opposite, provided that

$$B^2 = \omega \sin\lambda . \rho/\mu. \quad . \quad . \quad . \quad . \quad 4{\cdot}1$$

Accordingly the first two "laws of approach" meet the conditions of the problem, and the rapidity of the approach, which may be measured by B, is seen to vary inversely as the square root of the eddy viscosity.

In the foregoing discussion it is verified that the "laws" are con-

[1] The argument will not stand examination in detail as the process of averaging is too vague. A more elaborate treatment is given in Taylor's paper.

The difficulty is physical as well as mathematical. There is a tacit assumption that as far as horizontal velocity goes an ascending mass of air is a fair sample of the layer from which it comes. This is justified in that there is no apparent reason why air moving faster than the average should be thrown down rather than up. It will be noticed that by dealing with the average of momentum over a large area we avoid the consideration of the variations of static pressure which accompany the fluctuations of velocity. It is by pressure that momentum is interchanged between different masses.

Major Taylor reminds me that Dr. Stanton's measurements show that the variations of static pressure in an eddying wind are of sufficient magnitude to produce the observed variations in horizontal velocity.

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sistent with the proposed conditions. They may be derived from the conditions by solving the vector equation,[1]

$$\mu \frac{\delta^2}{\delta z^2} \mathbf{R} = \iota . 2\omega \sin \lambda \mathbf{R}, \quad . \quad . \quad . \quad . \quad 4{\cdot}2$$

which leads at once to

$$\mathbf{R} = \mathbf{R}_0 e^{-Bz} e^{-\iota Bz}, \quad . \quad . \quad . \quad . \quad 4{\cdot}3$$

provided that B satisfies 4·1.

5. *Theoretical Basis of Law III.*—To find the relation between the wind near the surface and the geostrophic wind we must discuss what happens in the lowest layer where the eddies circulate which come in contact with the ground. This layer, the mean velocity of which is V_0, is affected by the friction of the ground and by the resistance of obstacles large and small, which resistance is in the direction opposite to V_0. The layer is also affected by the interchange of momentum with the layers above it, equivalent to a drag in the direction of the tangent to the velocity spiral, by the general distribution of pressure, and by the rotation of the earth. The combined effect of the last two influences is known to be an acceleration at right angles to R, the "relative velocity."

Comparison of Taylor's Assumption with Guldberg and Mohn's.—Taylor's theory ignores the effects on the lowest layer of the general distribution of pressure and the rotation of the earth so that the only effects to be considered are the friction (opposite to the direction of motion) and the drag due to the eddies. These being equal and opposite, it follows that the angle between V and R is 135°. The underlying assumption is that the layer under discussion may be regarded as of infinitesimal thickness.

In the older theory of Guldberg and Mohn, pressure and rotation were taken into acccount, but eddy viscosity was not. According to this theory the angle between V and R was found to be 90°.

Justification of Taylor's Assumption.—To discriminate between the theories we have to discuss the relative magnitude of the forces acting on a layer touching the ground and of a certain thickness H. H may be so chosen that the eddies at the top of this layer circulate freely without reaching to the ground.

The inflow of momentum per unit area at the top of the layer is seen from the foregoing analysis to be $\sqrt{2}B\mu R$, where R is the "relative wind" at the height H. The resultant of the pressure distribution and of the apparent force due to the earth's rotation is for the unit of horizontal area $2\omega \sin \lambda . \rho R'H$, where R′ is the average "relative velocity" up to the height H. By 4·1 this force is $2B^2\mu R'H$, and its ratio to the drag on the upper surface is $\sqrt{2}BHR'/R$.

R′ and R are of the same order of magnitude. Comparison with observation shows that 1/B is comparable with 300 metres, and judging by the behaviour of smoke it would seem reasonable to take H as 10 metres in ordinary circumstances over land so that the ratio $\sqrt{2}BHR'/R$ is of the order 1/30. Thus of the four actions on this surface layer of

[1] The heavy type is used for vectors; multiplication by ι is equivalent to rotation through a right angle; multiplication by $e^{-\iota Bz}$ to rotation through an angle Bz. To verify the validity of the solution differentiate 4·3 twice, remembering that $(1+\iota)^2 = 2\iota$, and notice that $R = R_0$ when $z = 0$, and R approaches zero as z increases.

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thickness H, two, the general distribution of pressure and the rotation of the earth, produce an effect only one-thirtieth of one of the other two; these must therefore very nearly balance each other. Accordingly we are led to adopt as a good approximation Taylor's tacit assumption that the only forces that need be taken into account are the drag due to the eddies and the frictional forces. This assumption leads directly to the statement which has been set down as Law III. It should be noticed, however, that the average wind measured by an anemometer with a poor exposure may be much less than the wind at the height H, which is the wind "near the surface" of this law.

6. *Surface Friction.*—The relation between the wind "near the surface" and the "relative wind" at that level can be written down at once if it may be assumed that the surface friction per unit area is given by a formula of the type $K\rho V^2$ where K is a constant. The relation is obtained by equating the flow of momentum downwards from the upper layers to this frictional force, and is

$$\sqrt{2B\mu}R = K\rho V^2, \quad . \quad . \quad . \quad . \quad 6{\cdot}1$$

or, by 4·1,

$$KV^2 = \sqrt{2\omega \sin \lambda}\,.\,R/B. \quad . \quad . \quad . \quad . \quad 6{\cdot}2$$

By comparison of a wide range of experiments in the laboratory as well as on the large scale of the natural wind Taylor has justified[1] the formula $K\rho V^2$ and shown that K = ·0023 for Salisbury Plain.

A simple relation between V and G, which has been given by Taylor, may be learned from Fig. 2. If α is the angle between V and G whilst 135° is the angle between V_0 and R,

$$V_0 = G(\cos \alpha - \sin \alpha), \quad . \quad . \quad . \quad . \quad 6{\cdot}3$$

as may be seen by drawing the perpendicular CN from C or OP_0 produced and noticing that

$$\begin{aligned} OP_0 &= ON - P_0N = ON - CN \\ &= OC \cos \alpha - OC \sin \alpha. \end{aligned}$$

The total effect of surface friction in producing a flow of air across the isobars can be estimated by integrating equation 4·3. It is found that

$$\begin{aligned} \int_0^\infty \mathbf{R}dz &= \mathbf{R}_0 \int_0^\infty e^{-(1+i)Bz}dz \\ &= \frac{\mathbf{R}_0}{(1+i)B} \\ &= \frac{\mathbf{R}_0 e^{-i\pi/4}}{\sqrt{2}B} \quad . \quad . \quad . \quad . \quad . \quad 6{\cdot}4 \end{aligned}$$

Thus the integrated relative velocity is a vector whose magnitude is $R_0/(\sqrt{2}B)$ or $G(\sin \alpha)/B$, and whose direction, inclined at 45° to $\mathbf{R}_0$, is that of CN as defined above.

7. *Extension of the Theory.*—Hesselberg and Sverdrup have extended the theory involved in our Laws I. and II. to the case when the geostrophic wind instead of being the same at all heights changes in direction and magnitude.

The simplest assumption we can make is that the change in gradient is proportional to the increase in height so that the gradient γ at height z is related to the surface gradient γ_0 by a linear equation $\gamma = \gamma_0 + \alpha z$

[1] *London, Proc. R. Soc.*, **92** (Ser. A), 1916, p. 198.

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where γ and α are both vectors. A similar relation must hold between the gradient wind $\mathbf{G}$ and the surface gradient wind $\mathbf{G}_0$ so that we may write

$$\mathbf{G} = \mathbf{G}_0 + \mathbf{A}z. \quad . \quad . \quad . \quad . \quad . \quad 7{\cdot}1$$

The equation which expresses the equilibrium between the flow of momentum due to eddies, the pressure gradient, and the earth's rotation is

$$\mu \frac{\delta^2 \mathbf{V}}{\delta z^2} = \iota \,.\, 2\omega \sin\lambda \,.\, \mathbf{V}\rho - \iota \,.\, 2\omega \sin\lambda \,.\, (\mathbf{G}_0 + \mathbf{A}z)\rho, \quad . \quad 7{\cdot}2$$

and since

$$\frac{\delta^2}{\delta z^2}(\mathbf{G}_0 + \mathbf{A}z) = 0,$$

the substitution

$$\mathbf{V} = \mathbf{G}_0 + \mathbf{A}z + \mathbf{R} \quad . \quad . \quad . \quad . \quad 7{\cdot}3$$

leads to the equation

$$\mu \frac{\delta^2 \mathbf{R}}{\delta z^2} = \iota \,.\, 2\omega \sin\lambda \,.\, \rho\mathbf{R} \quad . \quad . \quad . \quad . \quad 7{\cdot}4$$

as before.

The integral of this equation being

$$\mathbf{R} = \mathbf{R}_0 e^{-\mathrm{B}z} e^{-\iota \mathrm{B}z}, \quad . \quad . \quad . \quad . \quad 7{\cdot}5$$

we learn that the "relative wind" veers and diminishes with increase of height according to the same law when the geostrophic wind changes uniformly with height as when it is the same at all heights.

8. *Modification of Law III.*—Near the surface we have

$$\mathbf{V} = \mathbf{V}_0 = \mathbf{G}_0 + \mathbf{R}_0 \quad . \quad . \quad . \quad . \quad 8{\cdot}1$$

and

$$\frac{\delta \mathbf{V}}{\delta z} = \mathbf{A} - (1 + \iota)\mathrm{B}\mathbf{R}_0. \quad . \quad . \quad . \quad . \quad 8{\cdot}2$$

The equation corresponding with 6·1 is

$$\mu \left(\frac{\delta \mathbf{V}}{\delta z}\right)_0 = \mathrm{K}\rho \mathbf{V}_0^2, \quad . \quad . \quad . \quad . \quad 8{\cdot}3$$

whence it follows that

$$e^{-3\iota\pi/4}\mathbf{R}_0 = \frac{1}{\sqrt{2}} \frac{\mathrm{K}\rho}{\mu \mathrm{B}} \mathbf{V}_0^2 - \frac{\mathbf{A}}{\sqrt{2}\mathrm{B}} \quad . \quad . \quad . \quad 8{\cdot}4$$

Let

$$\frac{\mathrm{K}\rho \mathrm{V}_0}{\sqrt{2}\mu \mathrm{B}} = a \text{ and } \frac{\mathbf{A}}{\sqrt{2}a\mathrm{B}} = \mathbf{U}, \quad . \quad . \quad . \quad . \quad 8{\cdot}5$$

then 8·4 may be written

$$e^{-3\iota\pi/4}\mathbf{R}_0 = a(\mathbf{V}_0 - \mathbf{U}), \quad . \quad . \quad . \quad . \quad 8{\cdot}6$$

indicating that $\mathbf{R}_0$ bears the ratio a to $\mathbf{V}_0 - \mathbf{U}$ and differs in direction from that vector by 135°. For a given value of V_0 and for eddies of a particular size a is a constant, and it is seen that the triangle whose sides represent $\mathbf{R}_0$, $\mathbf{V}_0 - \mathbf{U}$ and $\mathbf{G}_0 - \mathbf{U}$ is of a specified standard shape. This statement is the generalisation of Law III.

9. *Comparison of Surface and Geostrophic Winds in different Directions.*—Equation 8·6 may be used to determine the Geostrophic Wind corresponding with known values of V_0 and U. As to the magnitude of U, we note that it is not uncommon for East winds at the surface to be replaced by West winds at 2000 metres, so that we may take A as about G/2000; G is a variable in the present problem, so it is more convenient to take A as V/1000. As in § 3 the "relative wind" may be supposed to turn at the rate one degree in 6 metres; in that case $\mathrm{B} = \pi/(6 \times 180)$ and $\mathrm{U} = \cdot 25\mathrm{V}_0$ nearly. This proportion has been adopted in Fig. 4.

Under the convention adopted (the change in the gradient wind with increasing height being equivalent to the addition of a West wind) the

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diagram shows that the backing of the surface wind is least for South winds, greatest for North winds. The ratio for surface wind to gradient wind is least for a SE gradient wind and greatest for a NW one.

The convention is arbitrary; it is adopted merely to make the problem definite. To represent other cases, Fig. 4 should be orientated. The essential point to notice is the tendency for the surface wind to be governed by the geostrophic wind aloft rather than by the geostrophic wind at the surface.

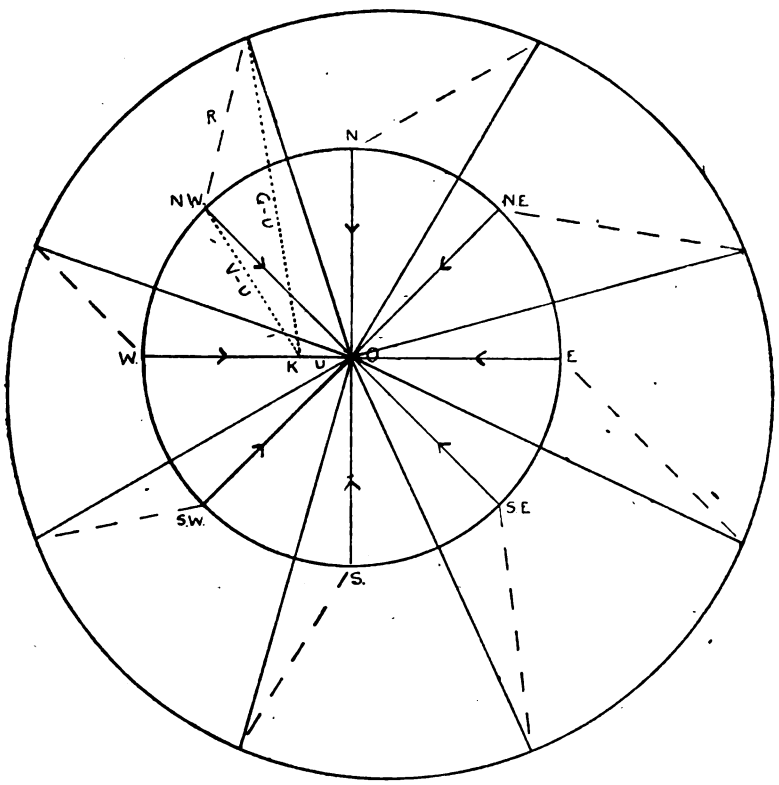

FIG. 4.—Relation of Geostrophic Wind to Surface Wind.

The strength of the Surface Wind is the same for all directions; the eddy viscosity is also the same; the change in Geostrophic Wind with increasing height is equivalent to the addition of a Westerly Component.

Theoretically there is no difficulty in deriving the lapse-rate for the geostrophic wind from a knowledge of the distribution of temperature: practically there are considerable difficulties as the knowledge is not available in a sufficiently precise form.

The most convenient formula for the rate of increase of the geostrophic wind is perhaps [1]

$$\frac{\delta G}{\delta z} = \frac{1}{\theta}\frac{\delta \theta}{\delta z} G + \frac{g\rho}{\theta}\Gamma, \quad . \quad . \quad . \quad . \quad 9{\cdot}1$$

where Γ is the gradient wind which would be found by calling the

[1] Cf. Shaw, *Manual of Meteorology*, Part IV., 1919, p. 82, 5 *b*.

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isotherms isobars and regarding the degrees as millibars, so that

$$2\omega\rho \sin\lambda \cdot \Gamma = \Delta\theta/\Delta n, \quad . \quad . \quad . \quad . \quad 9{\cdot}2$$

Δn being an element of the normal to the isotherms.

This formula shows at once that to the south of an area of low temperature there is an increase in the geostrophic wind from the west at greater heights, to the west of such an area there is an increase in the geostrophic wind from the north, and so on.

For rough numerical calculation we may take approximate values for θ and ρ and find

$$\frac{\delta G}{\delta z} = \frac{1}{2500}\Gamma + \frac{1}{300}\frac{\delta\theta}{\delta z}G, \quad . \quad . \quad . \quad . \quad 9{\cdot}3$$

the unit of height being the metre.

In the special circumstances for which Fig. 4 is drawn

$$\frac{\delta G}{\delta z} = \frac{1}{2000}G \text{ approximately,}$$

and therefore Γ is rather greater than G, *i.e.* the isotherms at 1a intervals must be closer than the isobars at 1 mb. The case is evidently an extreme one.

10. *Variation of Wind with Height for different Directions.*—The surface wind being known as well as the law governing the change in the geostrophic wind with increase of height, the actual wind at any height can be determined.

Figures 5*a* to 5*d* are drawn on the same assumptions as Fig. 4. In every 120 metres the West component of the geostrophic wind is increased by $\cdot 12V_0$, and the "relative wind" rotates through 20°, whilst its magnitude is reduced in the ratio 1 : $e^{\pi/9}$ or ·705 : 1.

Notwithstanding the differences in detail, the diagrams agree in making the wind equal in strength to the geostrophic wind at about 300 metres though the directions do not agree until a much greater height is reached.

11. *Comparison with Observations.*—An adequate discussion of the data available for comparison of the theoretical results with observation would necessitate the extension of this paper to an unreasonable length. Reference should be made to the papers already cited. The evidence for Laws I. and II. and their extension is quite satisfactory.

As to the third of the "Laws of Approach" and its extension in § 8, it must be emphasised that the wind "near the surface" must be measured at a considerable height with a free exposure. Probably the criterion adopted recently by the Meteorological Office in the specification of the Beaufort Scale, "10 metres above ground in the open," is sufficiently precise. The "Law" is satisfied fairly well by the Upavon observations where the anemometer head is at 30 metres and the angle between the recorded wind and the "relative wind" works out as 132° for light winds, 142° for moderate winds, and 134° for strong winds. For Paris, Åkerblom's averages lead[1] to 136° in winter and 139° in summer.

[1] Stockholm. *Arkiv för Matematik*, etc., vol. ii., 1916, No. 18, p. 6, Table I. The angle in question is $90° + \beta$. Other results quoted by Åkerblom show a large range in the value of β; in the majority of cases it is found to be less than 45°. If the recorded wind had been too low owing to bad anemometer exposure β would have been greater than 45°. Details as to the exposure of the anemometers are not given. Åkerblom has endeavoured

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In seeking for verification of the extended law in which direction is taken into account, it is to be remembered that conditions assumed in § 7

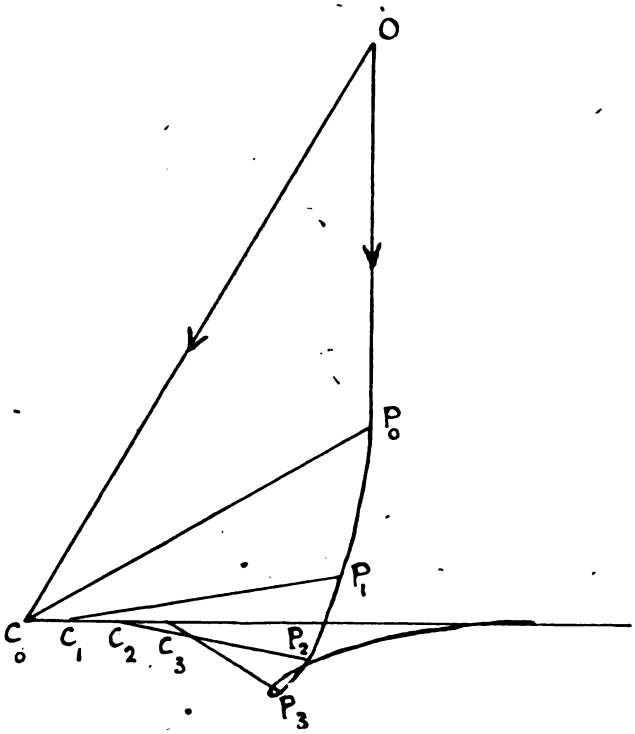

FIG. 5a.—Surface Wind from North. In this and the next three diagrams the Geostrophic Wind at the surface is represented by OC_0, that at 120 m. by OC_1, at 240 m. by OC_2, etc. The corresponding actual winds are represented by OP_0, OP_1, OP_2 . . .

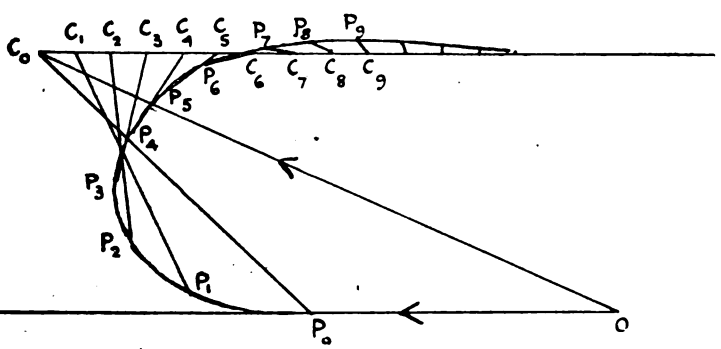

FIG. 5b.—Surface Wind from East.

are that the eddies are of like character for all wind directions, and that

to estimate β for ship observations on the Atlantic, but as the calculation depends on the table of equivalents of the Beaufort Scale, too much importance must not be attached to the result that $\beta = 50°$ on the average.

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no asymmetry is introduced by the topography of the area surrounding the station. There are few anemometers for which this last condition is satisfied. J. S. Dines's diagrams for Pyrton Hill and Southport

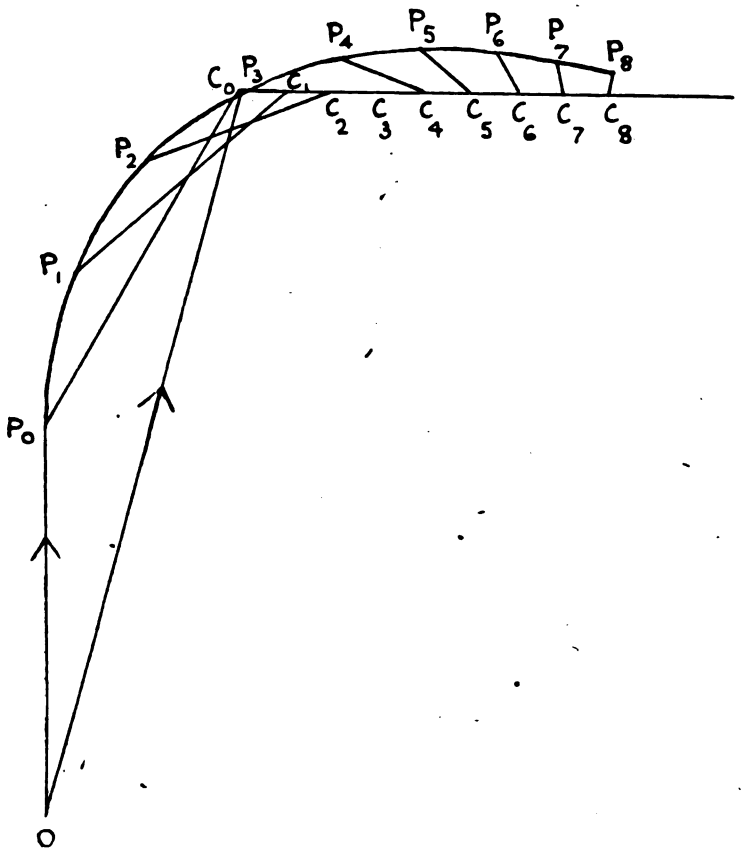

FIG. 5c.—Surface Wind from South.

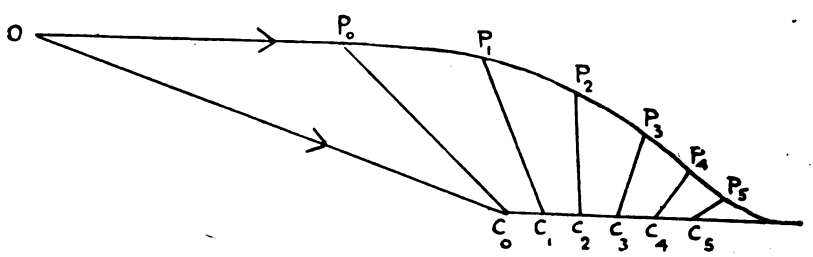

FIG. 5d.—Surface Wind from West. West Component of Gradient Wind increasing with height.

illustrate[1] the results obtained on the slope of a range of hills and on the seashore. Sir Napier Shaw has sought the explanation of the

[1] Fourth Report on Wind Structure. The diagrams are reproduced in the *Manual of Meteorology*, Part IV., p. 14.

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peculiarities of the Southport diagram in the possible "refraction" of the isobars in crossing a coast-line.

The wind observations at O-Gyalla, the principal meteorological station in Hungary, were selected for study by T. Koraen,[1] the station being continental, and offering, as he thought, the advantage of being exempt as far as possible from the perturbations to which high relief in the surrounding country might give rise. No description of the actual surroundings seems to be available however. The official account[2] of the observatory shows that the anemometers are mounted on a tower in

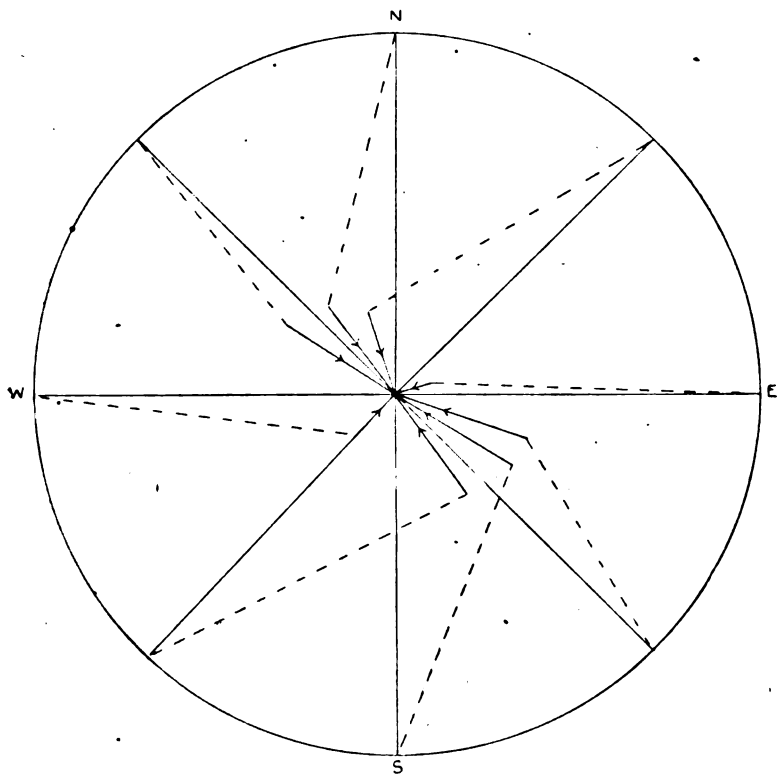

FIG. 6.—O-Gyalla (Hungary). Relation of the Actual Wind to the Geostrophic Wind. (7 h.; Low Pressure.)

well-wooded grounds, and, as shown in a photograph, the vane must have been 5 or 6 metres above the tops of the neighbouring trees in 1898. O-Gyalla is about 10 k. north of Komarom, a town on the Danube 100 k. north-west of Buda-Pest, and, judging by a small-scale map, the district, which is intersected by meandering streams, would appear to be flat. Whatever may be the cause, Koraen's results indicate that winds from SE or NW are comparatively strong, and suggest that the station is sheltered in some way on the NE and SW. The diagram (Fig. 6) which

[1] *Sur les relations du gradient barométrique avec le vent*, etc. Upsala, 1910.

[2] N. T. E. v. Konkoly: *Die Kön. ung. Reichsanstalt . . . und das Kön. ung. Meteorologische und Physikalische Observatorium in O-Gyalla*, Budapest, 1898, *vide* Plate II.

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has been drawn to represent the relation between surface wind and gradient wind corresponds with Koraen's data for low-pressure conditions.[1] Evidently verification of the Third Law of Approach is not to be expected in this case.

In the same paper Koraen has discussed observations made on the lightship at Horns Rev, 50 k. from the west coast of Jutland. These observations are Beaufort-scale estimates and systematic errors in reducing them to metres per second are, therefore, not unlikely.

Koraen's results for low-pressure conditions have been utilised for

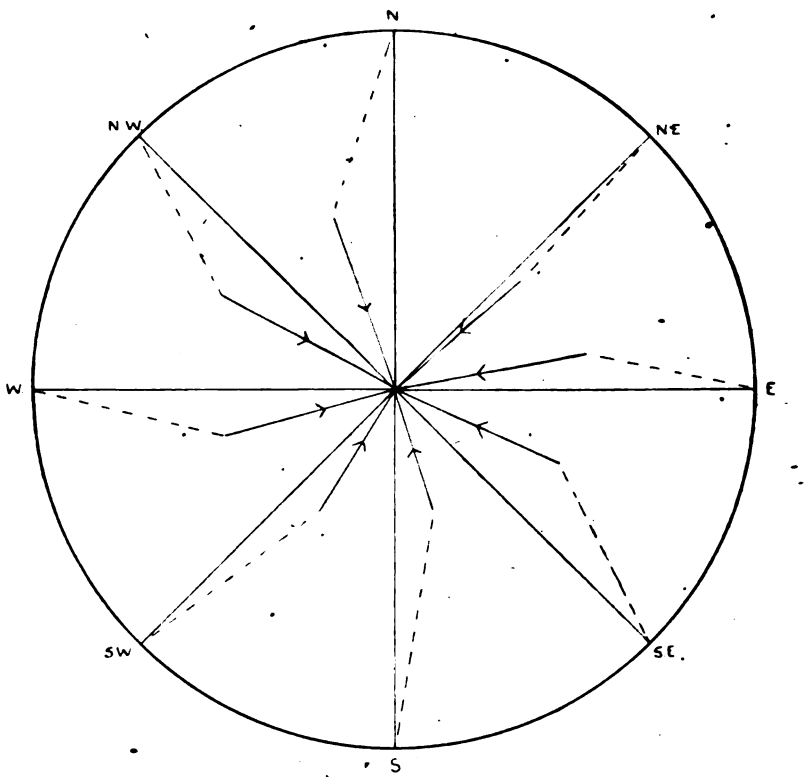

FIG. 7.—Horns Rev. Relation of Actual Wind to the Geostrophic Wind. (8 h.; Low Pressure.)

the diagram (Fig. 7). A curious feature is the slight veering from the isobars of NE winds, a phenomenon which is so anomalous as to suggest some error in computation. Apart from this detail, there is fair agreement with Fig. 4, winds from S being much lighter in comparison with the gradient winds than those from NW.

It should be pointed out, however, that there is an alternative explanation of this phenomenon.[2] A North wind is likely to be colder than the water over which it blows, and therefore, as it is heated from

[1] *l.c.* Tables. The unit gradient 1 mm. per degree corresponds with a gradient wind 8·8 m/s.

[2] Cf. Shaw, *Manual of Meteorology*, Part IV., 1919, p. 23.

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below, it will be unstable compared with a South wind which is generally being cooled from below. Accordingly the B of equation 4·1 is smaller for a North wind and the V of equation 6·2 is larger. The observations are not adequate for discriminating between these explanations.

One difficulty is that the reduction of Beaufort Scale estimates to metres per second is very arbitrary. It is to be hoped that opportunities will be found for erecting anemometers on lightships or on isolated lighthouses so as to provide more satisfactory material for the discussion of the relation between wind and pressure at sea.

DISCUSSION.

Capt. D. BRUNT called attention to Hesselberg and Sverdrup's diagrams of the spiral. They worked out a large number of results from pilot balloon observations and showed that the spiral is followed out very nearly up to the height at which gradient direction is reached and then the curve tended to shoot off to the right in rather a striking manner.

Mr. L. F. RICHARDSON said that Professor Bjerknes had told him that the original discoverer of the equiangular spiral was Ekman in 1905, but his paper being published in Sweden did not get through to this country. Mr. Whipple had generalised the spiral, and he hoped he would still further generalise it to fit the case in which the eddy motion varied with height. This had been mentioned in a paper by W. Schmidt[1] of Vienna, and he (Mr. Richardson) had found the same thing by an independent method. The viscosity at the ground is $\frac{1}{100}$ of what it is at the height of a kilometre, and this enormous variation with height ought to be taken into account. There were rapid variations in the first ten metres, as could occasionally be seen from frozen snow on a telegraph pole on a flat moor.

Sir NAPIER SHAW asked if Mr. Whipple could give a physical explanation of why the observed wind should be greater than the geostrophic wind itself, and if it was because of the following flow of upper parts of the eddies. It was a curious fact that by putting the ground in the way of the wind some of it was made to go faster than if the obstacle were not there. Was it possible on the analogy of the motion of an eddy with that of a rolling cart-wheel that there was a combination of the motion of eddy in upper regions with the motion of translation of the current? The geometrical explanation of these complex phenomena was very interesting, and with some further simplification Mr. Whipple's paper might become an appendix to Maxwell's *Matter and Motion*.

[1] *Wien, Sitzber. Ak. Wiss.*, IIa, **126**, 1917, H. 6 and IIa, **127**, 1918, H. 9.

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WINDS AND TEMPERATURE GRADIENTS IN THE STRATOSPHERE.

By G. M. B. DOBSON, M.A., F.R.Met.Soc.

[Received September 4—Read December 17, 1919.]

1. Winds in the Stratosphere.

Some years ago observations by "ballons-sondes" showed that while the troposphere is colder in cyclones than in anticyclones, the reverse is the case in the stratosphere, and it was pointed out that as a consequence of this the wind velocity must be reduced in the lower part of the stratosphere. Pilot balloon observations by Captain C. J. P. Cave tend to bear this out, but up to the present, few data, if any, have been collected in which both the distribution of temperature and the variation of wind velocity are known up to great heights. It was found that the results contained in the publications of the International Commission for Scientific Aeronautics contained some 70 cases where "ballons-sondes" had been followed by theodolites to heights well within the stratosphere, and gave satisfactory temperature and pressure records; and it was thought desirable to see what additional information these ascents would afford. Further, in most of the previous treatments of the subject, the means of a large number of individual cases have been given, these means having been taken for various heights above ground level; and in this way, since the height of the bottom of the stratosphere varies over a wide range, any effects which may occur at a height fixed relative to the stratosphere would tend to be obscured. The results used, have been those published in the International Commission's publications for the years 1904 to June 1912. Naturally, days with very light winds tend to predominate, since, when there are strong winds, balloons frequently get too far away to be observed with the theodolites before they reach a great height. A certain number of days with very light winds have therefore been discarded.

The method which has been used to work up the results is as follows:

For each selected day a diagram was plotted, showing the variations of temperature, wind velocity, and wind direction with height. The velocities recorded on these diagrams were then traced on to one sheet, so that the whole of the curves showing variation of velocity with height appeared as one composite picture. This was done for two cases: (*a*) in which heights were taken above mean sea-level, and shown in Fig. 1; and (*b*) in which the heights were taken from the base of the stratosphere Fig. 2. Two things are noticeable: firstly, within the troposphere the increase of velocity with height is roughly inversely proportional to the density, that is to say, the pressure gradient remains constant at all heights in the troposphere, a result which has often been found before. Secondly, as seen in Fig. 1, at some height between 8 and 14 k. nearly all the winds which have velocities over about 15 m/s in the troposphere fall off to velocities under 10 m/s.

Turning to Fig. 2, it is seen that this sudden decrease of velocity

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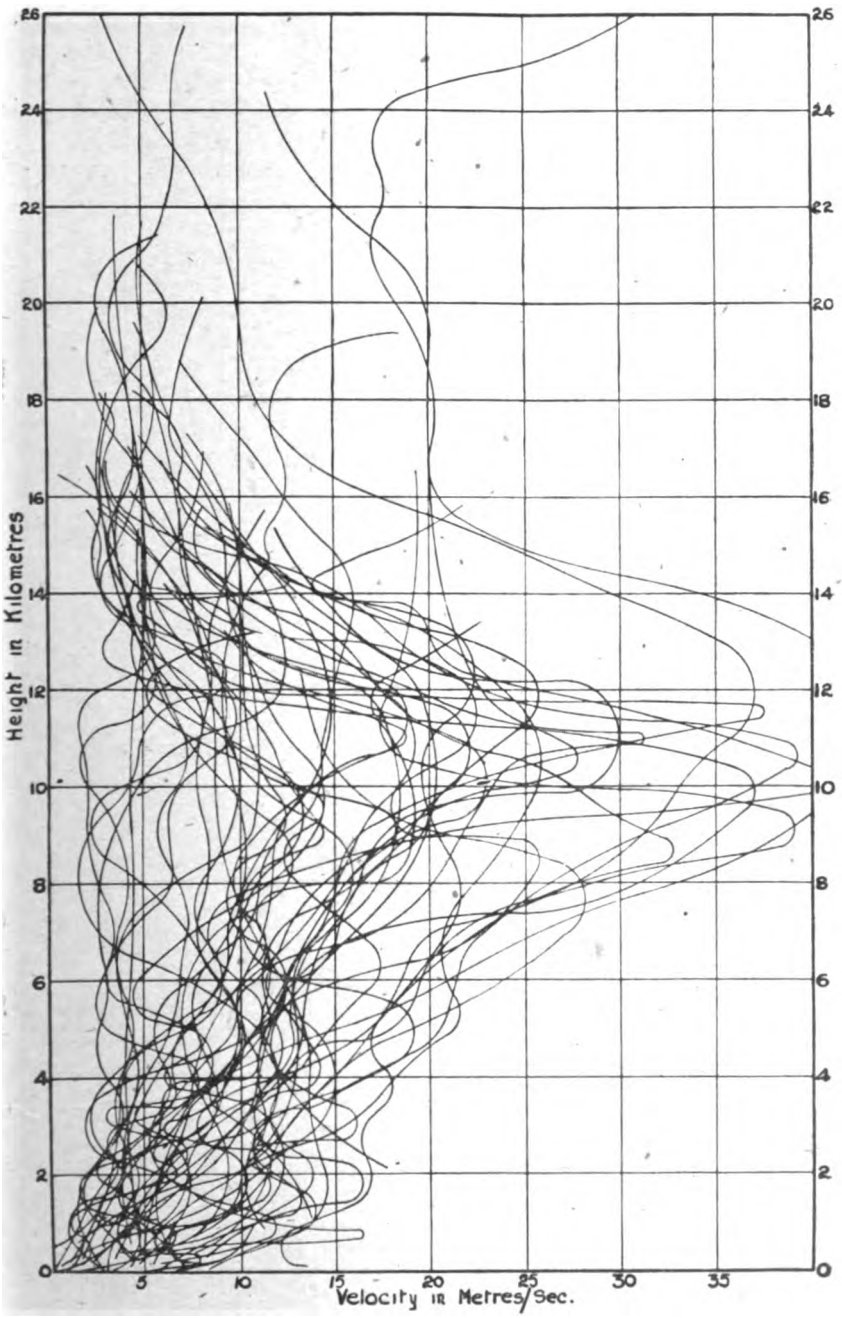

FIG. 1.—Variation of Wind Velocity with Height.
Heights are taken above mean sea-level.

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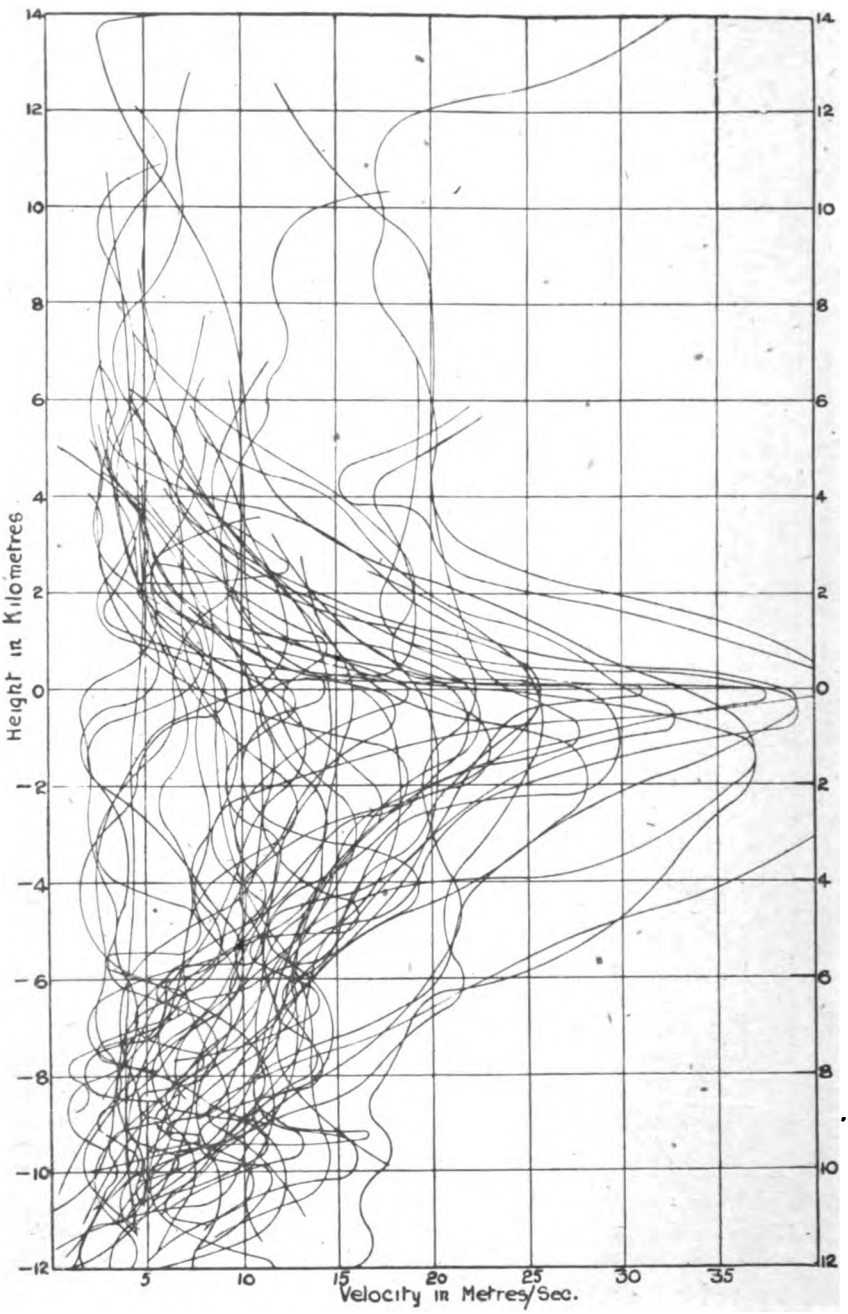

FIG. 2.—Variation of Wind Velocity with Height.
Heights are taken relative to the base of the stratosphere as given by temperature records.

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occurs in nearly every instance very close to the base of the stratosphere. The differences between the height at which the velocity suddenly decreases and that of the base of the stratosphere, as shown by the temperature records, are probably sufficiently small to be explained by errors in observation.

It was also found that the decrease in wind velocity on entering the stratosphere occurred just as much in high pressures as in low pressures, and when the stratosphere is high as when it is low. It seems, therefore, that we may take it as a general rule that whenever

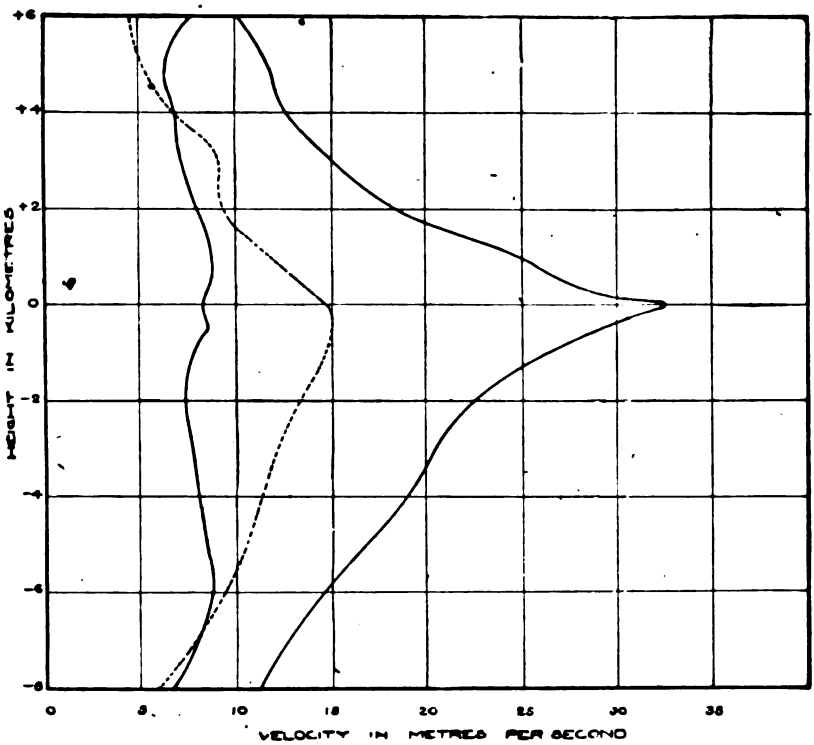

FIG. 3.—Mean Variation of Wind Velocity with Height.

Data are grouped according to wind velocity in the highest two kilometres of the Troposphere: (*a*) less than 13 m/s, (*b*) 13 to 19 m/s, (*c*) greater than 19 m/s. Heights are relative to base of the Stratosphere.

the velocity is fairly large, say above 15 m/s in the troposphere, it almost invariably decreases very suddenly within the stratosphere. For winds under 10 m/s there seems to be little change, in fact some of them appear to increase slightly on entering the stratosphere.

Fig. 3 shows the mean change of velocity with height (referred to the base of the stratosphere) for winds whose velocity in the highest 2 k. of the troposphere was (i.) 12 m/s or below, (ii.) 13 to 19 m/s, (iii.) 20 m/s and above.

The direction of the wind has been treated in the same way as the velocity, and the result is shown in Fig. 4, where heights are again referred to the base of the stratosphere, and not to the ground level.

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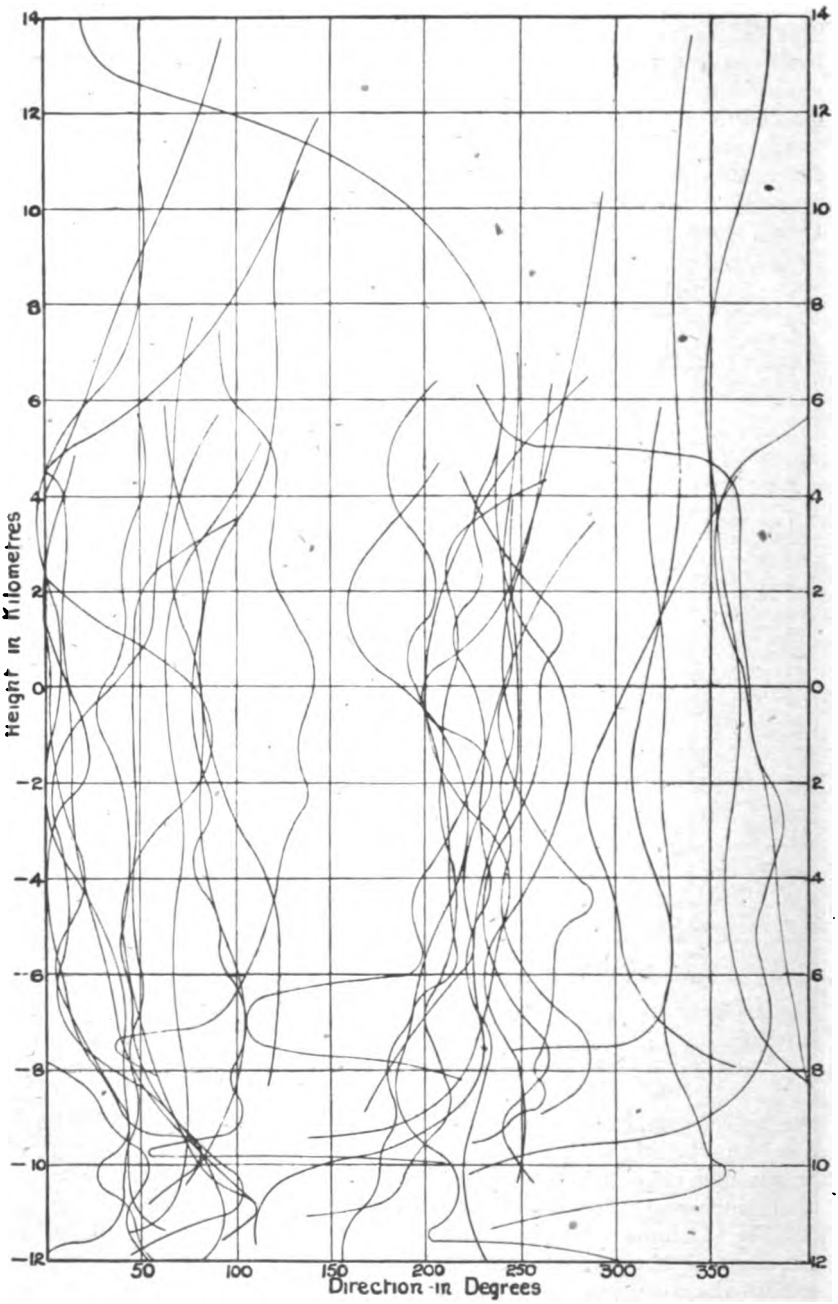

FIG. 4.—Variation of Wind Direction with Height.
Heights are relative to the base of the stratosphere as found from temperature records.

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Winds with velocities averaging under 10 m/s have been omitted from these diagrams, as, when the pressure gradient is so small, the direction has not much meaning.

We see at once that as soon as the surface layers are left behind, the direction becomes remarkably constant, and remains nearly the same from 4 k. up to the highest point reached. No effect whatsoever is seen in the direction on entering the stratosphere. In one or two cases only does the direction of these winds change at some great height, by approximately 180°.

The conclusion drawn from the whole set of diagrams is therefore that, omitting very light winds, the velocity within the troposphere increases at a rate which would occur if the pressure gradient remained constant, but falls off very rapidly, immediately on entering the stratosphere. The direction of the wind remains constant from 2 k. above the ground to a height of several kilometres above the tropopause.

2. Variation of Horizontal Pressure and Temperature Gradient with Height.

The variation of the wind with height, which has been discussed in the previous section, is so regular, that if we take a few typical days it is probably sufficient to show the variation of temperature gradient and pressure gradient with height.

The horizontal pressure and temperature gradients have been calculated by the usual methods (described in the *Computer's Handbook*[1]) from the observed wind velocity. It is assumed that the observed wind velocity is in equilibrium under the pressure gradient, and that the effect of curvature of the path is very small. Fig. 4 shows that there is very little change of wind direction with height, and it has therefore been assumed that the direction remained constant except in the cases where sudden large changes occurred within the stratosphere. The pressure gradient is that at right angles to the average wind direction. The velocity curves have been somewhat smoothed for the purposes of these calculations, as they then probably give more typical results, and the inaccuracies which necessarily occur in the measurements of the wind at great heights are partly avoided. Still, at great heights the results are necessarily somewhat uncertain, and too much reliance should not be placed on the exact values at the top of the curves.

Fig. 5 shows the variation of horizontal pressure gradient with height. It will be noticed that the gradient remains nearly constant throughout the troposphere, but suddenly begins to decrease with remarkable rapidity as soon as the stratosphere is entered. It appears to approach a value which is nearly zero at about 18 or 20 k. It may be well to point out that this does not imply that only very light winds will be found above this height. Even if the pressure gradient never increased above the value shown at the highest level for which results are available, the decrease in density would account for winds of considerable velocity. The results are, therefore, in no way contradictory to those obtained from the observations of meteor trails, etc., which indicate high velocities at great heights.

[1] *London, Meteor. Off.*, M.O. No. 223, Section II.

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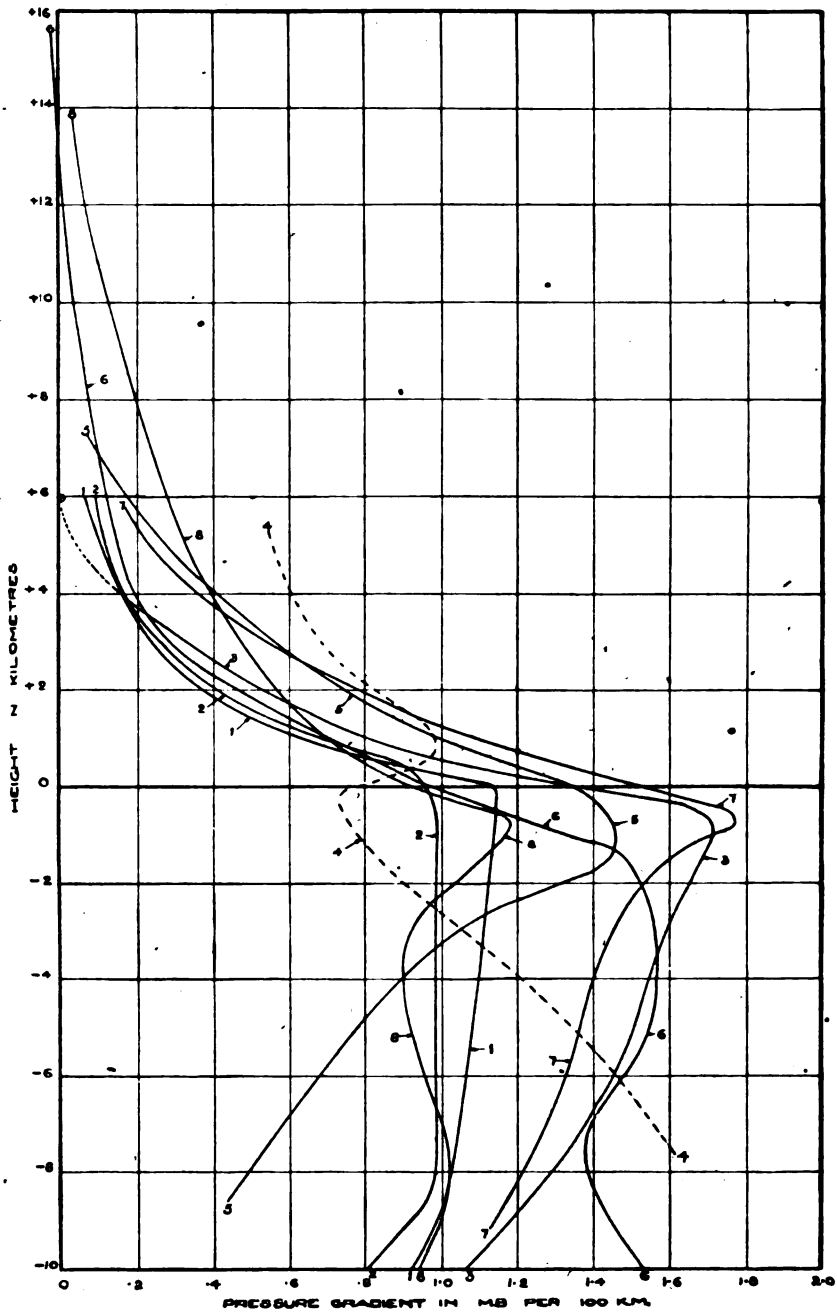

FIG. 5.—Variation of Horizontal Pressure Gradient with Height.
Heights are relative to the base of the stratosphere.

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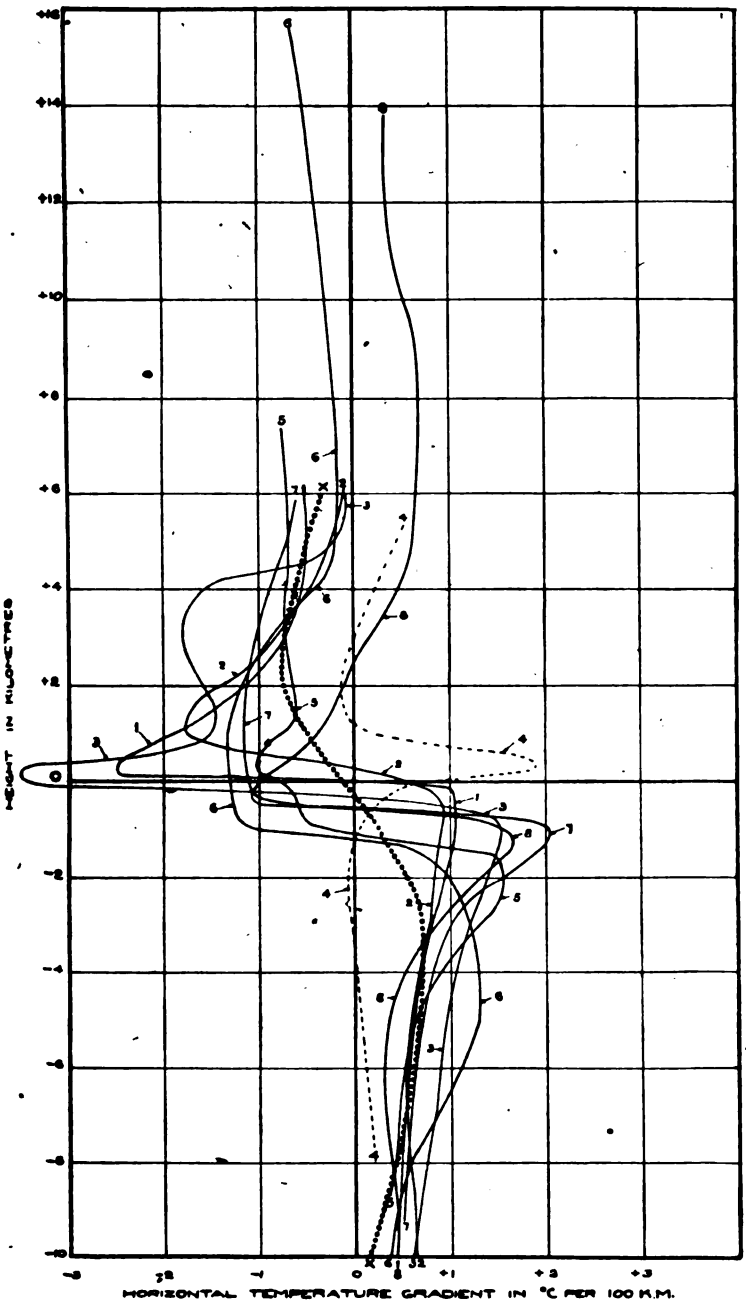

FIG. 6.—Variation of Horizontal Temperature Gradient with Height.
Heights are relative to the base of the stratosphere.

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Fig. 6 shows the horizontal temperature gradient for the same days. The gradient is the temperature gradient at right angles to the average direction of the wind. The general result is as follows:

Within the troposphere the temperature gradient increases gradually with height, the air being colder over the cyclone than over the anti-cyclone, but on entering the stratosphere a very sudden reversal takes place, and the gradient changes to a value somewhat greater than that at the top of the troposphere, and in the reverse direction. After a kilometre or two this value decreases again, and becomes very nearly zero at heights of 18 or 20 k. It appears uncertain whether it would quite reach the zero value at 20 k. The general result is in entire agreement with the temperature gradients which have been known to exist from the temperature records obtained from "ballons-sondes," but the striking point is the extremely sudden and large reversal which takes place just at the base of the stratosphere.

The figures against the curves in Figs. 5 and 6 indicate the date and place of the ascent thus:

1. 7th June 1906.—Strassburg.
2. 1st Oct. 1908.—Ditcham Park.
3. 7th May 1909.—Hamburg.
4. 8th Dec. 1909.—Trappes.
5. 14th April 1910.—Nijni Oltchedaeff.
6. 13th Sept. 1911.—Uccle.
7. 15th Sept. 1911.—Pawlowsk.
8. 13th April 1912.—Uccle.

All except No. 4 are quite typical of the usual velocity curves when there is an appreciable pressure gradient. No. 4 is added as an instance of an irregularity from the general rule. On this day the velocity remained nearly constant throughout the troposphere at about 12 m/s, and increased to about 19 m/s on entering the stratosphere, and remained constant at this velocity up to the highest point reached.

It will be noticed that in some cases the sudden change in the conditions began a little below the stratosphere. This is probably an error either in the height used in calculating the wind velocities, or in the temperature and pressure records. It does not seem possible that such a great change extending over a large area could occur, except when there was a sudden large change in the temperature lapse rate which occurred at different heights at different localities. The sudden changes are therefore almost certainly associated with the base of the stratosphere.

The dotted curve marked X in Fig. 6 is constructed from the temperature above various surface pressures given by Mr. W. H. Dines in *Geophysical Memoirs*, No. 2,[1] and from figures kindly supplied by him specially for this purpose for heights above 14 k. It is necessary to assume a horizontal pressure gradient for converting Mr. Dines's temperatures into temperature gradients, and that assumed by him in constructing Fig. 2 of the *Geophysical Memoirs*, No. 2,[1] has been used. Mr. Dines's figures relate to the height above sea-level, so that the sudden change which occurs at the base of the stratosphere is largely obliterated by the large variations in the height of the stratosphere. Within two kilometres on either side of the average height of the base of the stratosphere one would not expect this curve to agree with the individual ones. The agreement except in this region is quite good. In drawing the curve X the mean height of the stratosphere was taken as 11 k.

[1] *London, Meteor. Off.*, M.O. No. 210b, 1912.

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DISCUSSION.

Mr. L. F. RICHARDSON said that the diagrams in this valuable paper called attention to the suddenness of the changes at the base of the stratosphere in the clearest possible manner. But when variation of wind within the stratosphere had to be plotted he suggested that there was much advantage in plotting, not direction and resultant velocity, but rather the two components of velocity along any rectangular axes. The reason for this procedure is a theoretical one. If the temperature in each column is independent of height, and if the wind is geostrophic, then the following simple proposition is arrived at logically: *the rectangular components of velocity are in every case linear functions of height.* There is no such theoretical simplicity about the relation of either resultant velocity or direction to height. Some few observations which he had examined appeared to bear out the above proposition. Further comparison was desirable. The observational data to be used to test this proposition might be individual ascents or average of components, but must not have been averaged while expressed as directions and resultants.

Sir NAPIER SHAW said the paper verified what had been inferred not so many years ago from Captain Cave's observations. Though the wind fell off above the tropopause the direction of the wind did not vary much when the stratosphere was reached. The observations of direction of the wind there were very important. Mr. Dobson had cited about 31 cases of wind distribution, and of those 10 were from a SW septant and 12 from the two septants between N and NE, the other winds were distributed between other directions, but there were none directly from the S. That was not unlike the direction at sea-level. He had been trying to picture the distribution of velocity in the stratosphere, and hoped it was going to be a general motion of rotation of the cap of air round the pole as indicated by Teisserenc de Bort's isobars. But with an equal number of NE and SW winds there must be something like a cyclonic distribution. Was there a series of cyclones coming out of the north-west and passing on to the continent, and so giving a SW wind to begin with and a NE to end with, and was the existence of such meteors above the limit of convection to be contemplated? The only explanation that he could think of was that the run-down of the air from great heights on the slopes of Greenland might set up a circulation in the atmosphere above it exactly like the whirl in a basin with the plug out. The whirl being thus started the rest of the experiences would follow.

Mr. J. S. DINES wished to congratulate the author on his novel treatment in measuring heights from the base of the stratosphere in place of from M.S.L., and thus bringing out the really remarkable mean curve shown in Fig. 3 for strong winds. He would like to ask, however, whether the point of maximum velocity on this curve had not been slightly misplaced, as on the individual curves in Fig. 2 it seemed to be in almost every case slightly below the horizontal "o" line, whereas in the mean curve it was exactly on the line. The speaker would like to join issue to some extent with Mr. Richardson concerning the desirability of working with component winds rather than with direction and velocity. For some purposes components had undoubted advantages, but if in the present case the wind had been treated by components to E and to N, or along the surface pressure gradient and perpendicular to it, the nature of the remarkable change at the base of the stratosphere would not have shown up so clearly, and the method actually adopted seemed in this case to possess advantages. He was surprised to see how closely the horizontal temperature gradients in Fig. 6 worked out from individual pilot balloon ascents agreed with the mean gradient between cyclone and anticyclone as revealed by Mr. W. H. Dines's temperature measurements. The temperature gradient calculated from

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a pilot balloon ascent might be imagined to apply only over a small distance of the order, say, of 50 or 100 k., but the diagram seemed to show that really it could be taken as applying over a much greater distance, say 1000 k. in length.

Mr. F. J. W. WHIPPLE said that the fact that the biggest winds were at the border between the stratosphere and the troposphere indicated that the biggest centrifugal force was at that level and provided machinery for sucking air from above and below. The actual distribution of pressure and temperature in cyclones and anticyclones indicated that the cyclone was a region in which air was not rising of its own accord, but in which it was being sucked up from above. The fact that the greatest speed was at the tropopause gave the machinery for maintaining cyclones. He was surprised to hear the President say that a sharp distinction between the types of isobars in the stratosphere and troposphere was to be expected. The high correlation between pressures at different levels indicated that cyclones ought to be visible on maps drawn for, at any rate, the lower regions of the stratosphere.

Mr. W. H. DINES writes: Presumably most of the ascents used depend upon observations made with one theodolite only, and if so a correct measure of the velocity of the wind depends upon uniformity in the ascending velocity of the balloon. It has been asserted that the sudden change in the lapse rate on entering the stratosphere causes a discontinuity in the difference of temperature inside and outside the balloon, and if so a discontinuity in the ascensional velocity. I do not think the effect is of much consequence or vitiates Mr. Dobson's conclusions, but it is worth noting. A discussion of the whole subject will be found in the publications of Dr. A. Schmauss issued at Munich before the war. I am interested in Mr. Dobson's conclusion (Fig. 5) that the pressure gradient is nearly or quite zero, about 19 k. I reached the same conclusion by different means in "The Characteristics of the Free Atmosphere,"[1] where it is shown that at 20 k. there is very little change of mean pressure between station and station or cyclone and anticyclone.

Mr. G. M. B. DOBSON said, in reply to Mr. W. H. Dines, that he thought that errors in the assumed rate of ascent were largely responsible for the sudden decrease of velocity apparently occurring below the tropopause on several occasions. The errors in the calculated horizontal velocity due to changes in the rate of ascent of the balloon in the stratosphere could hardly affect the appearance of the curves shown. Replying to Mr. Richardson, he said he did not see the advantage of plotting components of the velocity in two directions at right angles in this case, since the direction of the wind remained roughly constant to the greatest height reached in nearly every case. If this were so the shape of the curves of the components must be similar to that of the velocity. He also pointed out that the reason why previous papers on this subject had arrived at contradictory results was because some considered mostly light winds, while others included strong winds. Taking account of the mean velocity of the winds, the results of previous work agreed very well with the curves of Fig. 3.

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[1] *London*, Meteorological Office, *Geophysical Memoirs*, No. 13, 1919, M.O. No. 220 *c*, p. 61.

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QUOTATIONS FROM THE DIARY OF SAMUEL PEPYS ON THE WEATHER.

By Captain C. J. P. CAVE, F.R.Met.Soc.

[Received October 14—Read December 17, 1919.]

In the *Quarterly Journal* of the Royal Meteorological Society for 1904 [1] there appeared an article on "Weather Notes in Samuel Pepys' Diary, 1659–1669." The extracts given were taken from one of the incomplete editions of the Diary, though the complete one was available at that date. The extracts are very inexactly given; there is considerable confusion in the dates of the year, not only in the first three months of the year, where some confusion is conceivable owing to the method of reckoning the commencement of the year, but in other cases also; such a well-known date as that of the Fire of London is given as 1667. Days and months have also been misplaced; for instance, the first snow seen by Pepys for three years, in November 1662, is given under February in the paper in question. For these reasons, and as I have noted weather references on 557 days, against 38 previously given, it seems that the complete extracts should now be available, and the following are all the references that I have found in Wheatley's edition of the Diary. I have made the extracts as short as possible. In all cases unless otherwise stated the notes refer to London or the immediate neighbourhood; in cases referring to other places I have added the locality in square brackets unless the context makes it clear what place is referred to. I have considered the year to begin on January 1st; thus January 1st, 1659–60, is given under 1660. It must also be remembered that in the seventeenth century the old style was still used in England, so that January 1st, for instance, corresponds to January 10th new style. The dates in this paper are those given in the Diary, *i.e.* old style.

Pepys cannot claim to be considered as a meteorologist; his references to the weather are such as any one might make in writing a diary or in correspondence. Sometimes a month or more passes without any reference to the weather; when Pepys was with the fleet or going down the Thames by water references are more numerous, as might be expected. It should be noted that Pepys' memory for meteorological events was not always good, and his remarks on the worst or best weather he remembers must be taken with caution; for instance, he says that the night of July 13th, 1667, was so hot that he lay with only a rug and a sheet over him, the first time certainly since he was operated on for stone (March 26th, 1658), probably the first time since he was a boy; on July 15th, 1668, it was so hot that again he lay with only a rug and a sheet over him, "the first night that I remember in my life that ever I could" do so.

The following is a short summary of the weather of the different years:

1660. The year began with a hard frost and snow; it thawed on January 10th, but froze again in the middle of the month. From the

[1] Vol. 30, 1904, p. 264

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end of March to the end of May, Pepys was with the fleet under Lord Sandwich, first in the Thames, then off Deal, and finally off the Dutch coast, whence the King was brought back to England. During this time weather notes are very numerous, but there is nothing very remarkable to record except very bad weather from the 11th to the 20th of May, with apparently an on-shore wind at Scheveningen, which is recorded as being exceptional for the time of year. There is nothing very noteworthy during the rest of the year, except a few days' frost in the second half of November.

1661. The early part of the year was very warm; roses were in leaf on January 21st, the roads were dusty, and many flies were about. February 19th is mentioned as "the first winter day we have had this winter," but even then it was raining, and there is no reference to frost or snow. On April 23rd, Coronation Day, there was a severe thunderstorm. May was wet, and by June 2nd they began "to doubt a famine." There were slight frosts in the early part of December.

1662. The winter was again very warm, "which do threaten a plague," and January 15th was "a fast day ordered by Parliament to pray for more seasonable weather." There was a frost on the 26th, but apparently an isolated one. Sometime just before February 25th there was a great gale which did widespread damage to trees. May was very fine and warm. The rest of the summer and autumn calls for no remark. On November 27th there was a fall of snow, "which is a rare sight, that I have not seen these three years." This was the beginning of a cold spell; there was skating in St. James's Park by December 1st, and there was heavy snow on the 7th and 10th. On the 12th there was a sudden thaw, but there was still ice in the Park on the 13th, when the Duke of York "would skate although the ice was dangerous." The thaw must have been both sudden and intense, as two of the Admiralty officials were nearly drowned on their way to Portsmouth.

1663. There was frost from February 1st, or perhaps earlier, till the 13th, with skating in the Park; then came "a monstrous thaw," and rain on the 17th. In March the weather was very changeable, with a thunderstorm on the 15th, and sleet on the 29th. The beginning of May was very hot, with a thunderstorm on the 5th which caused extensive floods near Northampton. The summer was very wet. Prior to June 30th the weather had been wet for "two or three months together," and on July 21st "parliament kept a fast for the present unseasonable weather"; nor are there signs of any improvement later in the summer; on August 28th there was "a very great frost they say abroad, which is much, having had no summer at all almost." Early in December there was some frost and snow, but it became warm again on the 10th.

1664. This winter seems to have been exceptionally warm on the whole; a little snow on March 21st is contrasted with the general mildness of the previous months. The summer was remarkable for numerous thunderstorms; "there was more thunder this year than of any man's memory, and so it seems in France and everywhere else." On August 10th there was a great thunderstorm, "with such continuous lightnings, not flashes but flames, that all the sky and ayre was light; and that for a great while, not a minute's space between new flames all the time." Towards the end of December a frost set in.

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1665. The frost continued till January 18th, when it thawed, but it froze again, and on the 26th mention is again made of "a change of the weather from a frost to a great rain." There were frosts in February and March, and on March 26th Pepys says, "The last winter hath been as hard a winter as any have been these many years." This was the year of the great plague of London, but the summer appears to have been normal. On November 22nd a frost began which lasted till the end of the month or later; it then seems to have been warm till December 11th or 12th, when a severe frost began; by the 18th the Thames was full of ice; on the 20th it was "troublesome" to cross by boat; on the 22nd "the river is frozen," though Pepys visited the Duke of Albemarle by water on the 24th. On the 27th a thaw had set in, though there was still much ice on the river.

1666. On January 24th there was a very great gale. February and March seem to have been dry; on March 18th "all cry out for lack of rain." There was another drought later, for on June 26th we read of rain "after a long drowth." Several thunderstorms are reported during the summer, but there was another drought in August, for when the great fire began on September 2nd Pepys says that everything was combustible after so long a drought. The general wind direction during the fire is seen from the entry for February 3rd, 1667, where it is recorded that pieces of burnt paper were carried by the wind as far as Cranborne near Windsor, which makes the wind direction between East-North-East and East. The drought continued till September 9th. After this date the weather seems to have been very changeable; probably a Westerly type prevailed till about December 10th, after which it was frosty till the end of the year.

1667. The frost continued, and the Thames was covered with ice on January 1st. On January 9th it thawed. February seems to have been warm till about the 25th, when a cold spell began which lasted till the middle of March; on March 6th the King said that it was the coldest day he had ever known in England, and the 7th seems to have been still colder. The end of March and the first three weeks of April seem to have been dry and warm; on April 21st it rained, "it not having rained for many weeks." There seem to have been a good many days of Easterly wind in June and July, which helped the Dutch when they came up the Thames; the month of July was dry till the 27th. The rest of the year calls for no special remark, except that no frost is mentioned, though November 10th was "mighty cold."

1668. There seems to have been no hard frost or snow this winter. March was mostly fine and dry with a drought that ended on April 4th. On May 22nd there was heavy rain in London and to the north, but none at Newmarket; the rainfall must have been very heavy, as it caused floods near London, at Cambridge, and at Brampton in Huntingdonshire. The end of September and the beginning of October seem to have been exceptionally fine and warm, "as good as summer in all respects." There was a frost on December 7th, but it seems to have been unusually warm during most of December, as Pepys says that he only put on a waistcoat at night on December 24th, "the first winter in my whole memory that ever I staid till this day before I did so."

1669. The early part of January was frosty and there was snow on

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the 13th. There are no weather entries for February, but the end of March was cold with several falls of snow.

The diary ends on May 30th of this year.

There seems no reason to suppose that the weather in this country differed much from that to-day. The winters of 1659–60 and 1664–65 seem to have been moderately cold; 1662–63, 1665–66, and 1666–67 were very cold; 1660–61, 1661–62, 1663–64, 1667–68, and 1668–69 were warm. In the winters of 1665–66 and 1666–67 the Thames was frozen. The summer of 1663 was very wet and that of 1666 was dry. There are several accounts of floods in the summer caused by heavy rains; possibly in the seventeenth century the river banks were not well looked after, and the roads were unmetalled, so that the effects of heavy rain would have been more felt than to-day.

The Duke of York, afterwards James II., seems to have been something of a meteorologist, for on April 4th, 1668, he told Pepys his rules for knowing the weather, and he apparently made a very good forecast on that day, but Pepys does not tell us what his rules were.

It may be interesting to note that the sounds of distant gunfire were frequently heard in London. On the first four days of June 1666 guns were plainly heard in London when the English and Dutch fleets were engaged off the North Foreland. On June 2nd Pepys went "into the Parke, and there we could hear the guns from the fleete most plainly," and later in the day he told the King and the Duke of York, and they also went into the Park to hear the guns. But though heard in London they were not heard on the coast; the Katherine Yacht saw the Dutch fleet on May 29th, ran from them, and came up the Thames on June 2nd, having heard no firing at all. Evelyn heard the guns near London and went down to the coast, but found that nothing had been heard at Deal. On June 4th Pepys writes: "So walking through the Parke we saw hundreds of people listening at the Gravell-pits, and to and again in the Parke to hear the guns, and I saw a letter, dated last night, from Strowd, Governor of Dover Castle, which says that the Prince [Rupert] come thither the night before with his fleete, but that the guns which we writ that we heard, it is only a mistake for thunder; and so far as to yesterday it is a miraculous thing that we all Friday, and Saturday and yesterday, did hear everywhere most plainly the guns go off, and yet at Deale and Dover to last night they did not hear one word of a fight, nor think they heard one gun. This added to what I have set down before the other day about the Katherine, makes room for a great dispute in philosophy, how we should hear and they not, the same wind that brought it to us being the same that should bring it to them: but so it is." All this is quite in accordance with the audibility of gunfire in recent years.

On July 25th the fleets met again in the North Sea, and when Pepys went to Whitehall he was told that in the Park "the guns are heard plain." Many went into the Park, and the King and the Duke of York went into the bowling green and upon the leads, to hear the guns; Pepys joined them, and "it was pretty to hear how confident some would be in the loudnesse of the guns, which it was as much as ever I could do to hear them."

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In 1667, on June 7th (see entry under June 8th), guns were heard at Bethnell Green when the Dutch Fleet had arrived off Harwich just before their famous attack on the Medway.

1660

Jan. 3rd. A great frost.

4th. It snowed hard all this morning, and was very cold.

5th. A great frost.

6th. Still a great frost.

8th. Very hard frosty weather.

10th. It being through the heat of the sun a great thaw and dirty.

15th. A cold day and a great snow.

16th. I staid up till the bell-man came by with his bell just under my window as I was writing of this very line, and cried, "Past one of the clock, and a cold, frosty, windy morning."

Feb. 3rd. A most pleasant morning and sunshine.

12th. A most pleasant day as ever I saw. . . . In the afternoon . . . walked half an hour in Moorfields, which were full of people, it being so fine a day.

19th. It raining very hard. [Later the same day,] It raining.

22nd. Raining.

23rd. A pretty fair morning.

27th. The weather rainy to Epping.

March 13th. It rained hard. [Huntsmore, Bucks.]

14th. Raining hard [at night].

20th. The weather still very rainy. . . . Then to Westminster, where by reason of rain and an Easterly wind, the water was so high that there was boats rowed in King Street and all our yard was drowned, that one could not go to my house, so as no man has seen the like almost, most houses full of water.

21st. The wind very high against us [*i.e.* from the East] and the weather bad.

22nd. The weather continuing very bad.

23rd. The weather being good I was not sick at all yet [on board ship in the Thames, Long Reach].

25th. A fair day [in the Long Reach].

27th. This morning the wind came about and we fell into the Hope [a reach of the Thames below Tilbury].

April 5th. Set sail . . . about noon, and came in the evening to Lee roads and anchored. . . . I spent all the afternoon upon the deck, it being very pleasant weather.

6th. We under sail as far as the Spitts. . . . In the evening, it being fine moonshine, I staid late walking upon the quarter-deck.

7th. This day about nine o'clock in the morning, the wind grew high, and we being among the sands lay at anchor; I began to be dizzy and squeamish.

8th. Very calm again . . . About noon set sail . . . We had a brave wind all the afternoon.

9th. We having sailed all night, were come in sight of the Nore and South Forelands in the morning, and so sailed all day. In the afternoon we had a very fresh gale.

11th. The wind all this day was very high [off Deal].

12th. This day the weather being very bad, we had no strangers on board. [Off Deal.]

13th. This day very foul all day for rain and wind . . . then to bed, and it being very rainy, and the rain coming upon my bed, I went and lay with

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John Goods in the great cabin below, the wind being so high that we were fain to lower some of the masts. [Off Deal.]

14th. The sea was this morning very high. [Off Deal.]

17th. A very pleasant afternoon, and I upon the deck all the day, it was so clear that my Lord's glass shewed us Calais very plain, and the cliffs were as plain to be seen as Kent, and my Lord at first made me believe that it was Kent. [Off Deal.]

19th. This day it has rained much. [Off Deal.]

30th. So we took boat and first went on shore, it being very pleasant in the fields. [Off Deal.]

May 1st. A very pleasant day. [Off Deal.]

11th. It blew very hard all this night. [Off Deal.]

14th. The weather bad; we were sadly washed when we came near the shore, it being very hard to land there. [Off Scheveningen] . . . It was a bright moonshine to-night [the Hague].

15th. The wind being very high, and we saw two boats overset and the gallants forced to be pulled on shore by the heels, while their trunks, portmanteaus, hats, and feathers, were swimming in the sea. . . . We were fain to wait a great while before we could get off from the shore, the sea being very rough. . . . The ship rolled so much I was not able to stand. [Off Scheveningen.]

18th. But the wind being very high that no boats could get off from the shore, we returned to the Hague.

20th. It not being yet fit to go off, I went to lie down in a chamber in the house . . . Commissioner Pett at last came to our lodging, and caused the boats to go off; so some in one boat and some in another we all bid adieu to the shore. But through badness of weather we were in great danger, and a great while before we could get to the ship. . . . This hath not been known four days together such weather at this time of the year, a great while. Indeed our fleet was thought to be in great danger. [Off Scheveningen.]

21st. The weather foul all this day also. [Off Scheveningen.]

23rd. With a fresh gale and most happy weather we set sail for England. . . . Under sail all night, and most glorious weather. [On board ship on Charles II.'s return to England.]

29th. It being a pretty fair day we could see above twenty miles into France. [Off Dover.]

31st. A fine evening. [Off Dover.]

June 16th. To my Lady Wright's and staid till it had done raining, which it had not done a great while.

23rd. Staid to see the King touch people for the King's evil. But he did not come at all, it rayned so; and the poor people were forced to stand all the morning in the rain.

July 5th. It rained this morning, which makes us fear the glory of this great day will be lost; the King and Parliament being to be entertained by the City. . . . I saw the King, the Dukes, and all their attendants go forth into the rain to the City, and it bedraggled many a fine suit of clothes. I was forced to walk all the morning in Whitehall, not knowing how to get out because of the rain. . . . Mr. Blackburn and I (it beginning to hold up) went and walked an hour or two in the Park.

16th. This morning it proved very rainy weather. . . . I to my office and did business there, and so home, it being then sunrise, but by the time that I got to my house it began to rain again.

17th. The day proving fair.

22nd. All this last night it had rained hard.

Aug. 4th. At night it being very rainy, and it thundering and lightening exceedingly.

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Sept. 12th. It being very rainy.

19th. It rained sadly.

Oct. 3rd. Rainy weather.

9th. A clear moonshine night.

14th. In the evening we went home through the rain by water.

Nov. 11th. Very cold and foul and rainy weather.

15th. Very cold upon the water [*i.e.* the Thames].

20th. A very hard frost, the first we have had this year.

Dec. 6th. A most pleasant moonshine night.

8th. The wind I observed was rose exceedingly before I went to bed.

9th. Being called up early by Sir W. Batten I rose and went to his house and he told me the ill news that he had this morning from Woolwich, that the *Assurance* . . . was by a gust of wind sunk down to the bottom. Twenty men drowned.

10th. Up exceedingly early . . . it being a very fine bright moonshine morning.

11th. Up very early this day, and . . . the weather was very bad and the wind high.

16th. [In the afternoon] it rained hard.

1661

Jan. 7th. Home, it being clear moonshine and after 12 o'clock at night.

17th. It began to be dark before we could come to Dartford and to rain hard.

18th. Though some rain, and a great wind in my face, I got to London at eleven o'clock.

21st. It is strange what weather we have had all this winter; no cold at all; but the ways are dusty, and the flyes fly up and down, and the rose bushes are full of leaves, such a time of the year as was never known in this world before here.

29th. A most glorious and warm day, even to amazement, for this time of the year.

Feb. 14th. Good weather, but pretty cold.

19th. Raining hard and bitter cold, the first winter day we have yet had this winter.

March 6th. My Lady being come home out of the country ill by reason of much rain that has fallen lately, and the waters being very high.

21st. The weather very foul.

22nd. The day very pleasant.

April 1st. I went away home, it being a brave moonshine.

3rd. At night into the garden . . . it being moonshine.

14th. Rain [after dark].

15th. A very foul morning. . . . I to Mr. Rawlinson's and there staid all the afternoon, it being very foul.

18th. Raining hard [after dinner].

19th. It being so foul that I could not go to Whitehall.

21st. In the morning we were troubled to hear it rain as it did, because of the great show to-morrow[1] . . . all our talk about to-morrow's show, and our trouble that it is like to be a wet day.

23rd. Coronation Day. . . . And strange it is to think, that these two

[1] "The King in the early morning of the 22nd went from Whitehall to the Tower by water, so that he might proceed from thence through the City to Westminster Abbey, there to be crowned."—*The Diary of Samuel Pepys*, edited by Henry B. Wheatley, vol. ii., p. 17.

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days have held up fair till now that all is done, and the King gone out of the Hall; and then it fell a-raining and thundering and lightening as I have not seen it do for some years.

May 20th. After dinner to the Mitre, and there sat drinking while it rained very much.

21st. To Deptford where we staid . . . and so took barge again. . . . While we were upon the water one of the greatest showers of rain fall that ever I saw.

29th. Took coach, and (the weather and ways being foul) went to Walthamstowe.

June 2nd. It rained very hard as it hath done of late so much that we begin to doubt a famine.

5th. Very hot weather.

6th. The weather very hot, this night I left off my waistcoat.

16th. At night resolved to hire a Margate Hoy, who would go away to-morrow morning, which I did and sent the things [for Lord Sandwich] all by him . . . hoping to have them as the wind now serves in the Downs to-morrow night.

30th. At last we met with the Duke of York, according to an order sent us yesterday from him, to give him an account where the fault lay in the not sending out of the ships, which we find to be only the wind hath been against them, and so they could not get out of the river. . . . The weather now very fair and pleasant, but very hot.

July 22nd. Up by three, and going by four on my way to London; but the day proves very cold, so that having put on no stockings but thread ones under my boots, I was fain at Bigglesworth to buy a pair of coarse woollen ones.

Aug. 3rd. I rode all the way to Cambridge [from Ware], my horse being tired, and myself very wet with rain.

5th. Early to Huntingdon, but was fain to stay a great while at Stanton because of the rain, and there borrowed a coat of a man for 6d. and so he rode all the way, poor man, without any.

24th. It rained hard [in the evening].

Sept. 1st. Last night being very rainy broke into my house, the gutter being stopped, and spoiled all my ceilings almost.

6th. To an alehouse while it rained, which kept us there I think above two hours, and at last we were fain to go through the rainy street home.

8th. A very wet night last night and to-day.

10th. By reason of rain we had ill walking.

23rd. To Stevenage, and staid till a shower was over, and so rode easily to Welling. . . . It was a very rainy night.

24th. We rose, and set forth, but found a most sad alteration in the road by reason of last night's rains, they being now all dirty and washy, though not deep.

26th. Rainy.

30th. This morning up by moonshine, at 5 o'clock.

Oct. 18th. The weather cold.

Nov. 4th. In the morning, being very rainy.

13th. It raining very hard I went home by coach.

19th. Cold weather.

28th. It rained [in the afternoon] . . . a fine moonshine night.

Dec. 8th. A frost.

11th. Went to Moorfields, and there walked, though it was very cold, an hour or two.

13th. At home all the morning, being by the cold weather, which for these two days has been frost, in some pain.

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22nd. By and by I took occasion from the rain now holding up (it raining when we came into church) to put my wife in mind of going to the christening.

26th. I and my wife to Moorfields to walk ; but it was most foul weather, and so we went into an alehouse.

1662

Jan. 15th. It is a fast day ordered by Parliament, to pray for more seasonable weather than it is, both as to warmth and every other thing, just as if it were the middle of May or June, which do threaten a plague (as all men think) to follow, for so it was almost the last winter ; and the whole year after hath been a very sickly time to this day.

21st. We have heard nothing yet how far the fleet hath got toward Portugall, but the wind being changed again, we fear they are stopped, and may be beat back again to the coast of Ireland.

26th. It having been a very fine clear frosty day—God send us more of them—for the warm weather all this winter makes us fear a sick summer.

Feb. 1st. Express is come from my Lord with letters, that by a great storm and tempest the mole of Argier [Algiers] is broken down, and many of their ships sunk into the mole.

14th. By coach, it raining hard, home, . . . and to bed.

25th. To the Coffee-house, where among other things the great talk was of the effects of this late great wind ; and I heard one say that he had five great trees standing together blown down. . . . We have letters from the forest of Deane, that above 1000 oakes and as many beeches are blown down in one walk there. And letters from my father tell me of £20 hurt done to us at Brampton.

March 4th. To Moore Fields, where we walked a great while, though it was no fair weather and cold.

6th. More news to-day of our losses at Brampton by the late storm.

27th. Very windy and rainy weather.

April 20th. My intention being to go this morning to Whitehall . . . it did rain, and the wind against me, that I could by no means get a boat or coach to carry me.

May 2nd. The hottest day that has been this year.

3rd. To supper and to bed, it being exceeding hot.

9th. A fine still evening.

11th. The bed so soft that I could not sleep that hot night.

19th. My wife walking and singing upon the leads till very late, it being pleasant and moonshine.

31st. This month ends with very fair weather for a great while together.

June 20th. The wind high.

July 6th. It began to rain [in the evening].

15th. About bedtime it fell a-raining, and the house being all open at top it vexed me.[1]

16th. In the morning I found all my ceilings spoiled with rain last night.

18th. At night to bed, being much troubled at the rain coming into my house, the top being open.

19th. In the afternoon I went upon the river. . . . It raining hard upon the water, I put ashore and sheltered myself, while the King came by in his barge. . . . But methought it lessened my esteem of a king that he should not be able to command the rain.

20th. But what troubles me most is that it has rained all this morning so furiously that I fear my house is all over water, and with that expectation I

[1] The roof had been taken off while alterations were being made to Pepys's house.

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rose and went into my house and find that it is as wet as the open street. . . . Removed all my books to the office and all day putting up and restoring things, it raining all day long as hard within doors as without.

21st. Up early . . . the weather cold and likely to rain.

22nd. I had letters from the Downs from Mr. Coventry; who tells me of the foul weather they had last Sunday [*i.e.* July 20th] that drove them back from near Boulogne . . . with the loss of their cables, sayles and masts.

23rd. To bed, quite out of sorts in my mind by reason that the weather is so bad, and my house all full of wet.

Aug. 1st. After dinner . . . by coach home, it raining hard.

3rd. Fine weather.

4th. It being very dark, and the wind rising and our waterman unacquainted with this part of the river, so that we were presently cast upon the Essex shore but got off again . . . we came to Erith, and there it began to be calm, and the stars to shine.

17th. Church being done and it raining I took a hackney coach.

18th. I home just before a great showre of rayne.

22nd. About three this morning I waked with the noise of rayne, having never in my life heard a more violent shower.

Sept. 5th. A cold windy morning.

19th. Walked by brave moonshine [at Deptford].

Oct. 10th. And so rid . . . to Cambridge, but the way so good that but for a little rain I had got very well thither.

14th. By moonlight most bravely all the way to Cambridge.

15th. Finding our horses in good case and the night being pretty light, though by reason of clouds the moon did not shine out, we even made shift . . . to reach London.

22nd. It raining hard, by coach home.

27th. It raining hard, by coach home.

Nov. 4th. It having rained, and do still, very much all night long.

17th. Eleven o'clock and it being fine moonshine.

27th. At my waking, I found the tops of the houses covered with snow, which is a rare sight, that I have not seen these three years.

28th. A very hard frost; which is news to us after having had none almost these three years.

30th. It is a bitter cold frost to-day. . . . Thus ends this month in great frost.

Dec. 1st. Over the Parke (where I first in my life, it being a great frost, did see people sliding with their skeates, which is a very pretty art).

2nd. So home, being cold, and this night first put on a wastecoate.

5th. Up, it being a snow and hard frost . . . took a turn or two in the garden, being very pleasant with the snow and frost.

7th. A great snow.

8th. Then into the Park to see them slide with their skeates.

10th. So great a snow that we could hardly pass the streets . . . it being very cold, and so home to supper.

11th. Up, it being a great frost upon the snow.

12th. From a very hard frost when I wake, I find a very great thaw, and my house overflown with it.

13th. To the Duke [of York] and followed him into the Park, where, though the ice was broken and dangerous, yet he would go slide upon his scates . . . a letter from Sir William how that he and Sir J. Minnes did very narrowly escape drowning on the road [to Portsmouth], the waters are so high.

17th. Raining.

19th. It being cold Mr. Lee and I did sit all day till three o'clock by the fire.

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22nd. Rode to Woolwich. . . . Here having staid a good while, we got up again and brought night home with us and foul weather.

25th. A most brave cold and dry frosty morning.

1663

Jan. 25th. A pleasant sunshine day though cold.

Feb. 1st. A fine frost [at night].

2nd. A great frost still . . . a turn in the Park seeing them slide [*i.e.* skate].

5th. A very great frost still.

8th. Up and it being a very great frost . . . to the Park and there walked finely, seeing people slide. . . . I walked home with much ado . . . the ways being so full of ice and water by people's trampling.

13th. A monstrous thaw after the long great frost, so that there is no passing but by coach in the streets, and hardly that.

17th. After dinner . . . it raining hard, which it has not done a great while now, but only frost a great while.

20th. The wind being very fresh [going down the river to Woolwich] . . . by oars to the Temple, it raining hard.

March 2nd. A fine day and a brave gale of wind [on the river near Woolwich].

13th. A most pleasant day.

15th. This day the weather, which of late has been very hot and fair, turns very wet and cold, and all the church time this afternoon it thundered mightily which I have not heard a great while.

26th. The sudden change of the weather from hot to cold.

28th. A very cold day and high wind.

29th. Raining and snowing very hard, which I did never think it would have done any more this year.

April 5th. Home to dinner, it raining.

20th. After dinner, it raining very hard.

23rd. A wet and cold day.

May 5th. It has been this afternoon very hot, and this evening also, and about 11 at night going to bed it fell a-thundering and lightening, the greatest flashes enlightening the whole body of the yard, that ever I saw in my life.

15th. Strange were the effects of the late thunder and lightning about a week since at Northampton, coming with great rain, which caused extraordinary floods in a few hours, bearing away bridges, drowning horses, men, and cattle. Two men passing over a bridge on horseback, the arches before and behind them were borne away, and that left which they were upon: but however one of the horses fell over and was drowned. Stacks of faggots carried as high as a steeple, and other dreadful things; which Sir Thomas Crew showed me letters to him about from Mr. Freemantle and others, that it is very true.

29th. It rained very hard, rain and hail, almost all the morning.

June 21st. Raining hard [in the morning].

26th. It raining hard . . . I walked into the Kings Bench Court . . . and there staid an hour almost, till it had done raining, which is a sad season, that it is said there hath not been one fair day these three months, and I think it is true.

27th. Raining hard [in the afternoon].

30th. This day being the only fair day we have had these two or three months. . . . The weather wet for two or three months together beyond belief, almost not one fair day coming between till this day, which has been a very pleasant, and the first pleasant this summer.

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July 1st. This morning it rained so hard (though it was fair yesterday, and we thereupon in hopes of having some fair weather, which we have wanted these three months).

8th. I slept till 7 o'clock, it raining mighty hard, and so did every minute of the day after sadly. But I know not what will become of the corn this year, we having had but two fair days these many months.

9th. Abroad, it raining. . . . So home . . . in case Mr. Moore should continue his mind to go to Oxford, which I have little mind to do, the weather continuing so bad and the waters high.

11th. After dining done to the Dock by coach, it raining hard . . . [later] it raining as hard as it could pour down.

12th. A very fine day, the best we have had this great while, if not this whole summer.

13th. A most pleasant and warm day.

17th. It being likely to rain again to-night, which God forbid.

19th. Foul weather.

21st. This day Parliament kept a fast for the present unseasonable weather.

27th. A much warmer day than yesterday.

Aug. 2nd. It raining a wonderful hard showre about 11 at night for an hour together.

16th. After supper home, it being extraordinary dark . . . we no sooner within doors but a great showre fell that had doused us cruelly if we had not been within.

17th. A cold night.

27th. A very cold day and a cold wind.

28th. It being cold all night and this morning, and a very great frost they say abroad, which is much, having had no summer at all almost.

Sept. 3rd. The wind very fresh [on the river at Greenwich].

11th. Raining hard.

14th. A very promising fair day.

21st. It being most curious weather from the time we set out [from Biggleswade] to our getting home.

25th. To Deptford, where it of a sudden did lighten, thunder, and rain so as we could do nothing but stay in Davis's house.

29th. Then in the evening, towards night, it fell to thunder, lighten, and rain so violently that my house was all afloat, and I in the rain up to the gutters, and there dabbled in the rain and wet half an hour.

Oct. 4th. My house being miserably overflowed with rayne last night.

19th. Waked with a very high wind, and said to my wife, "I pray God I hear not of the death of any great person, this wind is so high."

Nov. 9th. By a fair moonshine home.

Dec. 4th. By water . . . cold and wet and windy to Woolwich.

6th. A cold day, and it begun to snow (the first snow we have seen this year).

7th. A frosty morning. . . . At Whitehall I hear and find that there was the last night the greatest tide that ever was remembered in England to have been in this river: all White Hall having been drowned.

8th. The very cold weather which we have.

10th. The weather being become pretty warm again.

24th. Up betimes; and though it was a most foggy morning, and cold, yet with a gally down to Eriffe [Erith], several times being at a loss whither we went.

1664

Jan. 18th. 12 at night and went home in a great shower of rain, it having not rained a great while before.

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20th. The weather is now very warm.

28th. Very cold.

Feb. 5th. By water, a brave morning, to Woolwich.

10th. The weather being warm.

20th. Walked to Greenwich, it being a very fine evening.

24th. It being a very fine morning.

28th. Walked in the garden by brave moonshine with my wife above two hours, till past 8 o'clock.

March 1st. To Deptford, it being most pleasant weather . . . so walked home by moonshine, it being mighty pleasant.

12th. To Deptford [in the afternoon] . . . and then walking home it fell hard a raining.

13th. Foul weather.

21st. Up, and it snowing this morning a little, which from the mildness of the winter and the weather beginning to be hot and the summer to come on apace, is a little strange to us.

24th. By water to Greenwich, it being very foggy.

26th. The weather . . . turning sudden to rain did make it very unpleasant.

27th. It being fine moonshine with my wife an hour in the garden.

April 8th. Up betimes . . . and anon it begunn to be fair after a great shower this morning . . . [late in the morning] a mighty storm of rain and hail.

12th. Very foul weather.

13th. A mighty foul day . . . [later] it raining still.

22nd. I was called up this morning before four o'clock . . . so by water against tide, it being a little cool, to Greenwich; and thence, only that it was somewhat foggy till the sun got to some height, walked with great pleasure to Woolwich.

May 13th. Up before three o'clock, and a little after upon the water . . . by and by a rainbow appeared, the first that ever in the morning I saw, and then it fell a-raining a little, but held up again.

19th. Very rayny weather, which makes it cooler.

23rd. It raining mighty hard of a sudden [on the river between Woolwich and Deptford]. . . . So home, it raining terribly.

29th. Warm weather.

June 1st. Before the play was done, it fell such a storm of hayle, that we in the middle of the pit were fain to rise; and all the house in disorder.

11th. Very warm and pleasant.

12th. To sleep, but was easily wakened by extraordinary great rain.

19th. In the afternoon the greatest shower of rain of a sudden and the greatest and most continued thunder that ever I heard I think in my life.

20th. A very cold night last night.

26th. And so, it being rainy, and thundering mightily, and lightning, we returned [from Gravesend]. By and by the evening turned mighty clear and moonshine.

28th. Very hot.

July 3rd. Thundering and lightning all the evening, and this yeare have had the most of thunder and lightning they say of any in man's memory, and so it is, it seems, in France and everywhere else.

6th. It rained hard [after dark].

7th. A cool day.

9th. Because of the heat of the weather a good while.

17th. All the morning at my office . . . it raining hard.

19th. To Deptford a little, and thence home, it raining mightily and being cold.

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22nd. The moon shining bright, and fine warm fair weather.

29th. After dinner . . . it raining.

Aug. 5th. By night to Stevenage, it raining a little, but not much.

16th. Wakened about two o'clock this morning with the sound of thunder, which lasted for an hour, with such continued lightnings, not flashes, but flames, that all the sky and ayre was light; and that for a great while, not a minute's space between new flames all the time; such a thing as I never did see nor could have believed had ever been in nature. . . . And that accompanied with such a storm of rain as I never heard in my life. I expected to find my house in the morning overflowed with rain breaking in, and that much hurt must needs have been done in the city with this lightning; but I find not one drop of rain in my house, nor any news of hurt done. But it seems it has been here and all up and down the countrie hereabouts the like tempest, Sir W. Batten saying much of the greatness thereof at Epsum . . . home to bed, very stormy weather to-night for winde.

Sept. 1st. A sad rainy night, up and to the office.

4th. Cold weather.

25th. It raining, they sat talking with us all the afternoon.

27th. Lay long, sleeping, it raining and blowing very hard.

Oct. 9th. It being cold [at night].

10th. Up, and it being rainy.

16th. It raining, we set out, and about nine o'clock got to Hatfield [from Stevenage].

17th. Very cold.

18th. Home by coach, it raining hard [at night].

26th. Took a hackney coach I hired, it being a very cold and foule day, to Woolwich.

29th. A very foule rainy day, from morning till night . . . and so, it raining hard, home.

Nov. 9th. Called up . . . between two and three o'clock . . . by water with a gally down to the Hope, it being a fine starry night. . . . Thence not staying the wind blowing hard, I . . . returned to the Tower.

21st. A fine clear moonshine night, but very cold.

Dec. 8th. Raining hard [in the evening].

23rd. It being a bright night, which it has not been a great while, I purpose to endeavour to be called in the morning to see the Comet, though I fear we shall not see it, because it rises in the east but 16 degrees, and then the houses will hinder us.

24th. Having sat up all night till past two o'clock this morning, our porter, being appointed, comes and tells us that the bellman tells him that the star is seen upon Tower Hill; so . . . I to Tower Hill, it being a most fine, bright moonshine night, and a great frost; but no Comet to be seen.

31st. Past twelve at night, it being bitter cold. . . . I never have been in so good plight as to my health in so very cold weather as this is.

1665

Jan. 2nd. A most fine hard frost.

3rd. A great frost.

4th. A very hard frost.

5th. Up, it being very cold and a great snow and frost to-night.

8th. A very fine frosty day.

9th. Still a brave frost.

10th. Still very cold.

12th. The wind being easterly.

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17th. The weather becoming pretty warm, and I think and hope the frost will break.

19th. Up, and it being yesterday and to-day a great thaw it is not for a man to walk the streets, but took coach. . . . This day and yesterday, I think it is the change of the weather, I have a great deal of pain.

26th. The sudden change of the weather from a frost to a great rain on a sudden.

Feb. 2nd. A brave frosty day.

6th. This being one of the coldest days, all say, they ever felt in England.

17th. Bitter cold, and frost and snow, which I had thought had quite left us.

March 6th. A most lamentable cold day as any this year.

8th. A bitter cold day.

26th. The last winter hath been as hard a winter as any have been these many years.

April 21st. It being very pleasant, the dust being laid by a little rain.

23rd. Raining now and then, which it seems is most welcome weather.

May 13th. The weather being hot.

19th. By water to Greenwich at 8 at night, it being very fine and cool and moonshine afterward.

June 7th. The hottest day that ever I felt in my life, and it is confessed so by all other people the hottest they ever knew in England in the beginning of June . . . by water home, where weary with walking and with the mighty heat of the weather . . . walking in the garden till twelve at night, when it began to lighten exceedingly, through the greatness of the heat.

8th. It having lightened all night hard, and one great shower of rain.

13th. A most pleasant evening.

25th. At noon dined, and then I abroad by water, it raining hard.

July 8th. By 12 o'clock [at night] to Woolwich . . . but strange to think what a fine night I had down, but before I had been one minute on shore, the mightiest storm come of wind and rain that almost could be for a quarter of an houre and so left.

11th. At night . . . very hot beyond bearing.

16th. But it was most extraordinary hot that ever I knew it [in the afternoon].

19th. Very late I went away, it raining. . . . So away about 12 [at night] it raining hard.

31st. We were fain to stay there in the unlucky Isle of Doggs, in a chill place, the morning cool and the wind fresh.

Aug. 5th. Did walk through the rain [at Deptford].

6th. In the evening, it raining hard, down to Woolwich.

13th. A very wet day all day.

17th. Short of Gravesend it grew calm, and so we come to anchor, and to supper mighty merry, and after it, being moonshine, we out of the cabin.

Sept. 9th. A most cursed rainy afternoon, having had none a great while before. . . . Rained all the afternoon and evening.

10th. A very ill day . . . and so . . . about 4 or 5 o'clock, it blowing very hard, and now and then raining, and wind and tide being against us, Andrews and I took leave and walked to Greenwich [from Woolwich].

13th. A cold evening.

15th. A cold misling morning.

18th. [With the Fleet at the Nore.] The wind and tide was so strong against us that we could not get up to [the "Prince"] . . . it being very cold . . . the wind being high the ship (though the motion of it was hardly discernable to the eye) did make me sick. . . . We come into Chatham river where the water was smooth. . . . It being dark and it beginning to rain just

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as we got [to Chatham] . . . about 10 at night, it being moonshine and very cold, we set out [for Greenwich].

20th. [The plague] is encreased . . . which is quite contrary to all our hopes and expectations, from the coldness of the late season.

24th. [Off Greys, Essex] a very calm, curious morning.

25th. [Between the Nore and Chatham] it being calm. . . . In our way I was [surprised], and so were we all, at the strange nature of the sea water in a darke night, that it seemed like fire upon every stroke of the oare, and, they say, is a sign of winde.

Oct. 1st. Come to the fleet [at the Nore] about two of the clock in the afternoon, having a fine day and a fine winde.

9th. By water, it raining most miserably, to Greenwich.

11th. Against tide and in the darke and very cold weather to Woolwich [from Erith].

12th. Called up before day . . . and down [the Thames], it being horrid cold . . . by water, very cold, and to Woolwich where it was now noon.

16th. Very cold again.

25th. After dinner my Lord by a ketch down to Erith . . . it blowing these last two days and now both night and day very hard southwardly, so that it has certainly drove the Dutch off the coast.

26th. Down to Greenwich, the wind furious high.

Nov. 1st. A very foule day for rain and a hideous wind.

2nd. A horrible darke, and a windy night.

3rd. After dinner . . . with a brave gale and tide reached up that night to the Hope [from the Nore] . . . a horrible foule night for wind and raine.

7th. A cold, windy, rainy morning.

14th. Raining hard . . . and stopped my going, as I intended, to the buoy of the Nore, and great reason I had to rejoice at it, for it proved the night of as great a storme as was almost ever remembered.

15th. It was horrible foule weather . . . almost midnight and a furious, darke and rainy, and windy, stormy night.

20th. Took horse for Nonesuch . . . the ways very bad, and the weather worse, for wind and rayne. . . . It rained hard and blew, but got home very well.

22nd. Great hopes of a further decrease [of the plague] because of this day's being a very exceeding hard frost, and continues freezing. . . . Fear that our Hambro' ships at last cannot go, because of the great frost which we believe it is there.

23rd. It continuing to be a great frost.

25th. All our business is now about our Hambro' fleete, whether it can go or no this yeare, the weather being set in frosty.

26th. Before day to dress myself to go toward Erith, which I would do by land, it being a horrible cold frost to go by water . . . the way being very bad, that is, hard and slippery by reason of the frost, so we could not come to past Woolwich till night. . . . I walked with a lanthorne, weary as I was to Greenwich ; but it was a fine walke, it being hard frost.

27th. Bitter cold . . . [at night] frosty cold.

Dec. 12th. The weather setting in cold.

13th. The plague is encreased again this week, notwithstanding there hath been a day or two great frosts ; but we hope it is only the effects of the late close warm weather.

16th. A fearful cold, snowing day . . . to bed, it being a great frost.

17th. A very fine, cold, clear, frosty day.

18th. Betimes up, it being a fine frost. . . . Home by water to Greenwich, the river beginning to be very full of ice.

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20th. To Lambeth on foot, but it was a very fine frosty walke, and great pleasure in it, but troublesome getting over the River for ice. . . . the darke cold frosty night.

21st. Dined at Captain Cocke's at a good chine of beef, and other good meat; but being all frost-bitten, was most of it unroast.

22nd. But I see it is necessary that I do often make visits to my Lord Duke [of Albemarle] . . . and now the river is frozen I know not how to get to him. . . . The weather hath been frosty these eight or nine days, and so we hope for an abatement of the plague.

24th. Up betimes, to my Lord Duke of Albemarle by water.

27th. We took boat, and it being darke and the thaw having broke the ice, but not carried it quite away, the boat did pass through so much of it all along, and that with the crackling and noise that it made me fearful indeed. . . . A fine, clear, dry night.

1666

Jan. 10th. By storms Sir Jer. Smith's fleet is scattered, and three of them come without masts back to Plymouth.

23rd. A most furious storme all night and morning.

24th. By agreement my Lord Brunker called me up, and though it was a very foule, windy, and rainy morning, yet down to the waterside we went, but no boat could go, the storme continued so. So my Lord to stay till fairer weather carried me into the Tower to Mr. Hore's and there we staid talking an houre, but at last we found no boats yet could go, so we to the office. . . . Thence my Lord and I, the weather being a little fairer, by water to Deptford. . . . My Lord and I, the wind being again very furious, so as we durst not go by water, walked to London quite round the bridge, no boat being able to stirre; and Lord, what a dirty walk we had, and so strong the wind, that in the fields we many times could not carry our bodies against it, but were driven backwards. . . . It was dangerous to walk the streets, the bricks and tiles falling from the houses that the whole streets were covered with them; and whole chimneys, nay, whole houses in two or three places, blowed down. But, above all, the pales on London-Bridge on both sides were blown away, so that we were fain to stoop very low for fear of blowing off the bridge. We could see no boats in the Thames afloat, but what were broke loose, and carried through the bridge, it being ebbing water. And the greatest sight of all was, among other parcels of ships driven here and there in clusters together, one was quite overset and lay with her masts all along in the water, and keel above water.

Feb. 4th. It was a frost, and had snowed last night, which covered the graves in the churchyard.

5th. Raining . . . about seven o'clock.

11th. Can hear nothing of Sir Jeremy Smith's fleete, that went away to the Streights the middle of December, through all the storms that we have had since, that have driven back three or four of them with their masts by the board.

18th. A brave day.

23rd. It being fine walking in the morning, and the streets full of people again.

26th. Going home [from Windsor] and all in fine weather.

28th. A most curious dry and cold morning.

March 18th. Very fine, fair dry weather, but all cry out for lack of rain.

April 1st. A most pleasant warm day.

8th. Raining [in the morning].

17th. The weather foule.

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21st. A mighty hot and pleasant day.

29th. To bed after having my haire of my head cut shorter, even close to my skull, for coolnesse, it being mighty hot weather.

May 5th. About 11 I home, it being a fine moonshine, and so my wife and Mercer come into the garden, and . . . we sang till about twelve at night.

10th. Past six o'clock, and then abroad . . . back again late, it being wondrous hot all the day and night and it lightning exceedingly all the way we went and came, but without thunder.

14th. Very cool in the evening.

31st. Waked very betimes in the morning by extraordinary thunder and rain.

June 2nd. [Prince Rupert] did intend to sail from St. Ellen's point [Isle of Wight] about four in the afternoon . . . yesterday; which gives us great hopes, the wind being very fair, that he is with them this even [*i.e.* with the rest of the fleet then engaged with the Dutch in the North Sea].

4th. Into the Parke till 9 or 10 at night, it being fine moonshine.

17th. Fine weather.

20th. It having been these three or four days mighty hot weather.

25th. The weather being extremely hot.

26th. This afternoon, after a long drowth, we had a good shower of rain, but it will not signify much if no more come.

27th. Stood till the shower was over, it being a great and welcome one after so much dry weather.

July 7th. It proved the hottest night that ever I was in my life, and thundered and lightened all night long and rained hard.

15th. Mighty hot.

16th. A wonderful dark sky, and shower of rain this morning, which at Harwich proved so too with a shower of hail as big as walnuts.

25th. Most brave drink cooled in ice (which at this hot time was welcome).

Aug. 5th. A fine day . . . a mighty fine cool evening.

8th. A mighty fine bright night.

15th. So down below Greenwich, but the wind and tide being against us.

19th. We did also at night see Jupiter and his girdle and satelites, very fine, with my twelve foot glass.

22nd. And so up [onto the leads] to look upon the stars.

Sept. 2nd. The wind mighty high and driving it [the fire] into the City; and every thing, after so long a drought, proving combustible . . . the wind carries it into the City . . . [the fire] still encreasing, and the wind great . . . it being brave dry, and moonshine, and warm weather.

5th. A sad sight it was by moone-light [in the early morning] to see the whole City almost on fire . . . a great blessing it is to them [the people of London] that it is fair weather for them to keep abroad night and day.

7th. Our fleetes [the English and Dutch] have been in sight one of another, and most unhappily by fowle weather were parted.

9th. Took leave of my brother, whom I sent back this afternoon, though rainy; which it hath not done a good while before . . . and, it presently rayning, I was troubled for him, though it is good for the fyre.

11th. Come home in the rain.

15th. The late storm hindered our beating the Dutch fleete.

18th. It was a sad rainy and tempestuous night.

26th. Our fleete abroad, and the Dutch too for all we know; the weather very bad.

27th. A very furious blowing night all the night.

Oct. 12th. Mighty dirty weather.

14th. A very foul morning, and rained.

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15th. A very rainy morning.

18th. The waters so high in the roads, by the late rains, that our letters come not in till to-day.

21st. A mighty cool day.

22nd. The weather being very foul [in the morning] . . . it being very foule and darke [in the evening].

24th. About seven at night home, and called my wife, and, it being moonshine, took her into the garden.

Nov. 2nd. Very cold upon the water [between Woolwich and Deptford].

4th. Very cold.

9th. Ten at night, and rainy dirty weather.

15th. And so after supper, it being very cold, to bed.

16th. To bed, the weather being on a sudden set in to be very cold.

27th. A very foul day.

28th. It blows hard and rains hard.

29th. A wet afternoon.

Dec. 1st. In my way I did see a cellar in Tower Streete in a very fresh fire, the late great winds having blown it up.

10th. A cold day.

17th. In the evening . . . cold and dark.

23rd. Cold, and the ground all snow (at dusk).

24th. Frost and dry . . . snow upon the ground all day.

25th. A fine frost.

26th. A most fine frost.

28th. A very fine walk in the frost . . . a most horrid cold night it was, and frosty, and moonshine.

29th. At night, it being very cold.

31st. It being still a very great frost and good walking.

1667

Jan. 1st. A bitter, cold, frosty day, the frost being now grown old, and the Thames covered with ice.

2nd. My wife up, and with Mrs. Pen to walk in the fields to frost-bite themselves. . . . Walked home, it being mighty cold but dry, yet bad walking because very slippery with the frost and treading.

3rd. The frost continuing hard.

6th. An excellent frosty day.

9th. The way being most horribly bad upon the breaking up of the frost.

24th. A misly night, and very windy.

27th. A fine moonshine and warm night, it having been also a very summer's day for warmth.

30th. Eight at night, it being a little moonshine and fair weather.

Feb. 1st. It was a thick misty and rainy day.

3rd. Then we fell to talking of the burning of the City; and my Lady Carteret herself did tell us how abundance of pieces of burnt papers were cast by the wind as far as Cranborne [near Windsor].

13th. A foul evening this was to-night.

17th. I took boat, it being very fine moonshine.

27th. Up by candle-light, about six o'clock, it being bitter cold weather again, after all our warm weather.

28th. The weather for three or four days being come to be exceeding cold again as any time this year.

March 1st. Very cold weather again after a good deal of warm summer weather.

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3rd. A fine but very cold day.

6th. The weather, too, being become most bitter cold, the King saying to-day that it was the coldest day he ever knew in England . . . by water home, wondrous cold.

7th. This day was reckoned by all people the coldest day that ever was remembered in England.

14th. A fine clear day.

16th. The weather is now grown warm again, after much cold.

24th. A brave evening.

30th. A most summer evening.

31st. A fine day.

April 1st. After dinner . . . fine weather.

4th. Mighty pleasant weather . . . the weather being mighty pleasant.

12th. It being most sweet weather.

19th. A fine moonshine evening.

21st. It raining a little [in the evening] which is mighty welcome, it having not rained in many weeks, so that they say it makes the fields just now mighty sweet.

24th. 10 at night . . . and walked home by moonshine.

28th. After dinner . . . the day being mighty pleasant.

May 1st. Up, it being a fine day.

3rd. A most curious clear evening, after some rain to-day.

5th. A fine evening.

12th. A fine day.

26th. Up sooner than usual on Sundays, and to walk, it being exceeding hot all night (so as this night I begun to leave off my waistcoat this year) and this morning.

27th. A most sweet day.

28th. The weather and garden pleasant.

31st. To the office, where the weather so hot now-a-days that I cannot but sleep before I do any business.

June 5th. It being a most windy day, and hath been so all night, South West, and we have great hopes that it may have done the Dutch or French fleets some hurt.

9th. To a church . . . which was so full and the weather hot that we could not stand there . . . a most excellent evening.

10th. A most excellent fine evening.

14th. The easterly gale and spring-tides [when the Dutch fleet came up the Thames and Medway].

20th. To bed, miserable hot weather all night it was.

30th. Very fine weather, and the cool of the morning [about three a.m.] . . . [later at Chatham] raining hard.

July 4th. Hot weather.

13th. Up pretty betimes, it being mighty hot weather, I lying this night, which I have not done, I believe, since a boy, I am sure not since I had the stone before, with only a rugg and a sheet upon me.

July 14th. A very fine day . . . [at Epsom] it growing hot in the sun . . . the day being wonderful hot . . . there being a fine breeze abroad.

21st. By moonshine . . . very fine and pleasant.

24th. A letter from the Clerke of the Cheque at Gravesend to me to tell me that the Dutch fleete did come all into the Hope yesterday noon. . . . But these fellows are mighty bold, and have had the fortune of the wind easterly this time to bring them up, and prevent our troubling them with fire-ships ; and, indeed, have had the winds at their command from the beginning . . . the moon shining, and it being a fine pleasant cool evening.

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27th. It raining this day all day to our great joy, it having not rained, I think, this month before, so as the ground was everywhere so burned and dry as could be ; and no travelling in the road or streets in London, for dust.

Aug. 4th. It being very hot weather again.

11th. The morning is a very cold morning.

12th. It being cold now in the mornings . . . [later in the day] it raining.

13th. A dark and rainy night.

16th. The sudden change of the weather cold.

23rd. A fine evening.

Sept. 13th. The afternoon proved very foul weather, the morning fair.

15th. After dinner . . . it rained.

23rd. A mighty pleasant day.

25th. A mighty wet day and night.

Oct. 7th. So we to Enfield . . . it being but a foul, bad day.

8th. To Cambridge, it being foul, rainy weather . . . then took my wife, and W. Hewer, and Willet, it holding up a little, and showed them Trinity College and St. John's library.

11th. [On the road between Brampton and Stevenage] a pleasant day.

12th. [Between Stevenage and London] the weather very good all day and yesterday.

Nov. 10th. Mighty cold.

11th. It being now [probably in the late afternoon] and having been all this day a most cold and foggy, dark thick day.

25th. At night . . . it was mighty dark and foul.

Dec. 25th. A fine, light, moonshine morning.

1668

Jan. 11th. Cold, frosty weather [at night].

27th. Weather like the beginning of a frost and the ground dry.

Feb. 1st. A fine day.

6th. Dark and raining.

March 4th. A cold and wet day.

8th. Raining [in the evening].

15th. Fine dry weather.

18th. Mighty pleasant weather.

19th. A mighty fine, clear spring morning.

23rd. A very fine day.

April 4th. The Duke of York did tell us what rules he had, of knowing the weather, and did now tell us we should have rain before to-morrow, it having been a dry season for some time, and so it did rain all night almost ; and pretty rules he hath, and told Brouncker and me some of them, which were such as no reason seems ready to be given . . . my Lord Brouncker and I into the Park, and there took a great deal of ayre, saving that it was mighty dusty.

6th. By the last night's rain very pleasant and no dust. In the afternoon, stepping with the Duke of York into St. James's Park, it rained : and I was forced to lend the Duke of York my cloak.

7th. Away to the Park, which is now very fine after some rain.

17th. A most pleasant evening, moonshine.

25th. The weather being very hot.

30th. This being a mighty cold day.

May 1st. To the King's playhouse . . . and a disorder in the pit by its raining in, from the cupola at top, it being a very foul day and cold . . . by water not being able to get a coach, nor boat but a sculler, and that with company, it being so foul a day.

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10th. Took to water again [from Chelsea] . . . it raining all the way.

14th. The weather being very hot.

16th. To bed, after Nell's cutting of my hair close, the weather being very hot.

19th. A very rainy day.

22nd. Fitted myself for my journey to-morrow, which I fear will not be pleasant, because of the wet weather, it raining very hard all this day; but the less it troubles me because the King and Duke of York and Court are at this day at Newmarket, at a great horse race, and proposed great pleasure for two or three days, but are in the same wet.

23rd. To Bishop's Stafford [Stortford] and there dined. . . . Here . . . in comes Captain Forster . . . who had been at the late horse races at Newmarket, where the King now is, and says that they had fair weather there yesterday, though we here, and at London, had nothing but rain, insomuch that the ways are mighty full of water, so as hardly to be passed.

24th. Through the waters with very good success, though very deep almost all the way, and got to Brampton . . . [later] it raining a little, and the waters all over Portholme and the meadows, so as no pleasure abroad.

25th. [At Brampton] the first fair day, and yet not quite fair, that we have had some time . . . got well to Cambridge, the waters not being now so high as before . . . the river being mighty high by Barnewell Abbey.

26th. Got to Bishopsgate before eight [p.m.], the waters being now most of them down.

June 30th. Then home to dinner, where a stinking leg of mutton, the weather being very wet and hot to keep meat in.

July 15th. Wonderful hot all day and night, and this the first night that I remember in my life that ever I could lie with only a sheet and one rug.

16th. It being these two days excessively hot.

17th. To the King's house . . . a sorry mean play, that vexed us to sit in so much heat of the weather to hear it. . . . The weather excessive hot. . . . I only with a sheet and rug [on the bed], which is colder than ever I remember I could bear.

25th. A very rainy day.

Sept. 6th. A fine day.

20th. Mighty pleasant weather.

21st. [Night] mighty dark, but still weather.

27th. It being most summer weather that ever was seen.

28th. A most summer-like day, and a fine warm evening.

Oct. 11th. Most people being now come home to town, though the season of the year is as good as summer in all respects.

18th. It again being a rainy evening.

Nov. 2nd. A cold morning.

Dec. 7th. The first frosty day we have had this winter.

24th. A cold day . . . at night home to supper, and it being now very cold, and in hopes of a frost, I begin this night to put on a waistcoat, it being the first winter in my whole memory that ever I staid till this day before I did so.

1669

Jan. 1st. [Night] it being dry and moonshine.

3rd. This frosty weather, it being this day the first, and very hard frost, that hath come this year, and very cold it is.

5th. The frost and cold continuing.

6th. [Night] moonshine and fine frost.

8th. Cold weather.

12th. It being mighty cold.

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13th. Walked out into the Park, all in the snow.

21st. Frosty.

23rd. Seven at night . . . dark and foul weather.

March 5th. A mighty fine afternoon . . . the spring beginning a little now to appear, though the way be dirty.

14th. I to walk in the garden, the first time this year, the weather being mighty temperate.

23rd. Dined at Dartford . . . it being a cold day.

24th. [At Chatham] it being a mighty cold and windy, but clear day . . . Almost twelve at night . . . walked over the fields, as dark as pitch, and mighty cold and snow.

25th. [At Chatham] it having been a great snowy and mighty cold foul day.

27th. All the morning as cold, snowy, windy, and rainy day, as any in the whole winter past, but pretty clear in the afternoon.

April 5th. Very cold [in the morning].

18th. This being the first day of rain we have had many a day, the streets being as dusty as in summer . . . walked through the rain to the Temple.

25th. The weather very pleasant.

May 1st. The day looking as if it would be fowle . . . the day was very lowering . . . the day also being unpleasing, though the Park full of coaches, but dusty and windy, and cold, and now and then a little dribbling rain.

2nd. To the Park, and there spent the evening with much pleasure, it proving clear after a little shower.

6th. A noble day.

9th. To the Park, and there till night, being fine weather . . . very hot weather.

13th. A rainy foul day.

14th. A most pleasant day after yesterday's rain, which lays all the dust.

16th. Good weather.

30th. To the Park, whence the rain sent us suddenly home.

DISCUSSION.

Sir NAPIER SHAW asked that the thanks of the Society be given to Capt. Cave for collecting the extracts and putting them on record in the *Quarterly Journal*.

Mr. J. E. CLARK said he was interested to notice that the Diary confirmed the theory of the audibility of the guns, which were heard in London and not at Dover, and chiefly in the months of June and July, the months of most audibility in the recent war.

BACK NUMBERS OF THE QUARTERLY JOURNAL.

The Council of the Society would be glad if Fellows who have no longer any use for their copies of the following numbers of the *Quarterly Journal* would return them to the Society:—

Numbers **121** (January 1902), **122** (April 1902), **141** (January 1907), **142** (April 1907), **162** (April 1912), and **181** (January 1917); also any numbers previous to **28** (1878); also any spare copies of the reprints of the *Phenological Report*, especially those previous to the year 1911.

Binding Cases.—Binding cases for the *Quarterly Journal* can be obtained from the Assistant-Secretary, post free, price 1s. 8d.

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PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

November 7, 1919.

Ordinary Meeting.

Sir NAPIER SHAW, F.R.S., President, in the Chair.

A Lecture was delivered by Prof. V. BJERKNES, Hon. Member, of the Geophysical Institute, Bergen, on "THE STRUCTURE OF THE ATMOSPHERE WHEN RAIN IS FALLING." This Lecture will be published later.

November 19, 1919.

Ordinary Meeting.

Mr. F. J. W. WHIPPLE, M.A., Vice-President, in the Chair.

WILLIAM ANDREWS, 11 Railway Approach, Coulsdon ;

Lieut. CYRIL A. BROOK, R.A.F., Trinity House, Batley Carr, Batley ;

Capt. The Hon. RALPH A. COCHRANE, R.A.F., Crawford Priory, Springfield, Fife ;

JOHN L. COPE, B.A., British Imperial Antarctic Expedition, 66 Victoria Street, S.W.1 ;

FRED. CRUICKSHANK, c/o Williams Deacons Bank, Market Place, Higher Broughton, Manchester ;

Capt. I. GEORGE LE BOUTILLIEUR DIAMOND, Spencer House, Stansted ;

Capt. CHARLES KENNETH MACKINNON DOUGLAS, 12 Princes Square, Bayswater, W.2 ;

Lieut. CECIL WILLIAM DUFFIELD, R.A.F., R.N. Air Station, Pulham ;

Lieut. EDWARD J. GOODFELLOW, R.A.F., B.Sc, 20 Rochester Road, Southsea ;

RICHARD FRANCIS TURNEY GRANGER, Lenton Fields, Nottingham ;

Capt. SIDNEY PHILIP HOLLOWAY, R.A.F., 20 Mornington Road, N.W.1 ;

Flt.-Lieut. THOMAS CLIFTON BREWER HOOKE, R.A.F., 64 West Cromwell Road, Earl's Court, S.W.5 ;

Lieut. ARTHUR WEBB ISHERWOOD, R.A.F., 6 Leconfield Road, Highbury, N.5 ;

WILLIAM CYRIL KAYE, B.Sc., 11a Hemstall Road, West Hampstead, N.W.6.

ERIC WILFRID KITCHIN, Assoc.M.Inst.C.E., Markonia, Egmont Road, Sutton, Surrey ;

RICHARD KNIGHT, Manna Mead, 17 The Grove, Blackheath, S.E.10 ;

Dr. VILHELM FERDINAND VALDEMAR LINDHOLM, Statens Meteorologisk-Hydrografiska Anstalt, Stockholm ;

Dr. STANLEY FOX LINTON, M.Sc., D.P.H., The Old Mill, Cloughton, Scarborough ;

Lieut. ANGUS WILLIAM MACKAY, R.N.V.R., 242 Ladbroke Grove, W.10 ;

DAVID JOHN MARES, Commonwealth Weather Bureau, Sydney, N.S.W. ;

SIDNEY MORTIMER, Wigmore, Beare Green, Surrey ;

WILLIAM BERNARD MURPHY, F.R.S.A., A.F.R.Aë.S., St. Columban's College, Shrule, Co. Galway ;

FREDERICK HENRY NEWMAN, B.Sc., A.R.C.S., University College, Exeter ;

Dr. VEDARANYESVARA VAIDYANATHA RAMANA-SASTRIN, F.R.A.S., F.Z.S., Vedaraniam, Tanjore District, S. India ;

Lieut. ROBERT STEWART, R.A.F., M.A., Ladeside, Newmilms, Ayrshire ; and

THOMAS JOHN WILLIAMS, 7 Market Street, Rhyl,

were balloted for and elected Fellows of the Society.

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The following communications were read :—

1. "The Effect of High Temperature, Humidity and Wind on the Human Body." By Lieut. C. W. B. Normand, F.R.Met.Soc. (p. 1).

2. "Some Observations of the Upper Air over Palestine." By Capt. A. J. Bamford, M.C., F.R.Met.Soc. (p. 15).

3. "Barometric Pressure and Underground Water-Level." By E. G. Bilham, B.Sc., F.R.Met.Soc. (p. 35).

December 17, 1919.

Ordinary Meeting.

Sir Napier Shaw, F.R.S., President, in the Chair.

Nur Chand Ahluwalia, Ambala City, India ;

Frank Worsley Baker, Yateley Lodge Cottage, Yateley, Hants ;

George Auburne Clarke, The Observatory, King's College, Old Aberdeen ;

Lieut. William Morris Cooke, R.N.R., 57 Tufnell Park Road, N.7 ;

Paul de Rome, 3 Chase Mansions, Gondar Gardens, W. Hampstead, N.W.6 ;

Victor Albert Jarvis-Clark, 18 Elsie Road, East Dulwich, S.E.22 ;

Ernest Maurice Maurice, 6 Denbigh Street, S.W.1 ;

Capt. Leonard Frank Plugge, R.A.F., B.Sc., A.F.R.Aë.Soc., Royal Air Force Club, 13 Bruton Street, W.1 ;

Capt. Harold Hans Marshall Spink, Assoc.M.Inst.C.E., P.W.D. Secretariat, Bombay ;

George Thomson, Junr., 47 Cairnfield Place, Aberdeen ;

Richard George Veryard, 40 Richmond Avenue, Shoeburyness ;

Lieut. Douglas Charles Way, R.N.R., Indian General Navigation and Railway Co., Ltd., Calcutta ; and

Percy Raymond Zealley, 6 Waterloo Road, Cambridge Town, Shoeburyness,

were balloted for and elected Fellows of the Society.

The following communications were read :—

1. "The Laws of Approach to the Geostrophic Wind." By F. J. W. Whipple, M.A., F.R.Met.Soc. (p. 39).

2. "Winds and Temperature Gradients in the Stratosphere." By G. M. B. Dobson, M.A., F.R.Met.Soc. (p. 54).

3. "Quotations from the Diary of Samuel Pepys on the Weather." By Capt. C. J. P. Cave, F.R.Met.Soc. (p. 65).

At the invitation of the President, Sir Henry Lambert of the Colonial Office exhibited to the Meeting a MS. Weather Diary for the years 1781–1782. In introducing Sir Henry Lambert the President said that Sir Henry had been kind enough to come and show to the Fellows a weather diary kept by his great-grandfather in the years 1781–1782, and had offered to lend it for copying. It was very desirable that a copy should be added to the considerable number of historical MSS. on the weather preserved in the Society's library. He hoped that some day some one would find time to collate these and other old records and assemble in separate volumes of maps the information about the weather for each year, going as far back as the records permitted.

Sir Henry Lambert in exhibiting the MS. said that he believed, though there was no record on the face of the document, that the observations were taken at Muscovy Court, Tower Hill. His great-grandfather made no claim to being a scientist, but he had kept regular barometer and thermometer observations and notes of the wind and weather.

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CORRESPONDENCE AND NOTES.

The Meteorology of New Year Island, 1902–1905.

The meteorological and magnetic observatory on New Year Island, now also a wireless station, is situated in lat. 54° 39′ S., long. 64° 10′ W., and was established by the Argentine Minister of Marine at the beginning of the year 1902 to co-operate in the international Antarctic campaign.[1] The strictly Antarctic portion of the results obtained from this campaign was derived from the participating Expeditions "DISCOVERY," "GAUSS," "SCOTIA" and "ANTARCTIC," the reports of which were published at intervals between the years 1907 and 1915. It is only recently that a copy of the important series of observations made at New Year Island has reached this country, and I have taken the first opportunity of working up the results in order that the data may be available for discussion in connection with the more southern stations. The meteorological results are contained in four large quarto volumes, giving the hourly observations of the various climatic elements *in extenso*, while vol. 1 gives the hourly and other magnetic data, including the term day observations.[2]

According to the Argentine Sailing Directions[3] the group of small islands known as Islas Año Nuevo (New Year Islands) are five in number, the largest and most easterly on which the observatory is situated being located 16 miles to the west of Cape San Juan (St. John), the easternmost harbour of the neighbouring Staten Island to the north-east of Cape Horn. Unlike this island, which is mountainous with peaks rising to a height of 3000 feet and covered with snow most of the year, the New Year Islands are relatively flat, and have a much smaller rainfall than Staten Island. It is somewhat remarkable that although as stated the observatory was specially set on foot in connection with the Antarctic Campaign no use appears to have been made of the data. At any rate the station does not appear among those from which observations were sent to the Meteorological Office, London, in connection with the preparation of the Daily Synchronous Charts 1st October 1901 to 31st March 1904.[4] In the volumes under notice the hourly and other data are published *in extenso*, including complete observations at Greenwich noon, but there is no introduction giving a description of the methods of observation, instrumental equipment, and other particulars, such as usually appear in works of this nature, nor is any general summary of the results given either in the annual volumes or for the whole period.

The observations, however, appear to have been carefully made with good instruments, principally supplied by Richard, and Nordenskjöld, who visited the station on 6th January 1902 on his way to the Antarctic, refers to "the magnificent meteorological observatory with its valuable apparatus,"[5] while from a photograph that faces p. 586 of the undermentioned work[5] some idea of the general surroundings and outdoor installation (both of which appear to be excellent) have been obtained.

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[1] *London, Geog. J.*, **18**, 1901, pp. 15, 279.

[2] República Argentina, Ministerio de Marina, *Resultados del observatorio "Isla de Año Nuevo."*

Tomo 1	Magnetismo 1902–1905	Buenos Aires	1912, pp. 381.
Tomo 2	Meteorología 1902	,, ,,	1915, pp. 159.
Tomo 3	Meteorología 1903	,, ,,	1913, pp. 190.
Tomo 4	Meteorología 1904	,, ,,	1914, pp. 184.
Tomo 5	Meteorología 1905	,, ,,	1915, pp. 188.

[3] *Derrotero Argentino* (2nd Edition 1917), p. 344.

[4] *National Antarctic Expedition 1901–1904 — Meteorology*, Part 11. . . . London (published by the Royal Society), 1913. (See List of co-operating stations on p. 7.)

[5] Otto Nordenskjold, *Antarctica*, London, 1905, p. 20.

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The hourly observations as published have had to be revised, as in many cases when an instrument failed to record for a few hours no attempt was made to interpolate the missing values, with the result that the hourly, daily and in some cases the monthly means were subject to alteration after these had been filled in. The effect was most pronounced in the hourly means of pressure, many of which as printed were seriously out. A considerable number of other anomalies also showed up, which in nearly every case were adjusted by recomputing. The critical methods adopted in the fresh reduction of the data were such as to lead to the elimination of most of these errors, but it would be sanguine to imagine that all sources of error have been disposed of, although I believe that those remaining are insignificant and unlikely to exert any material weight on the broad results shown in the tables.

Table I. gives a general summary for the months and the year of the more important climatic elements, and Table II. shows the departure from the mean of the day of the hourly values of pressure, temperature, wind velocity and relative humidity for the seasons and for the year. The diurnal range of vapour pressure is so small that only the annual means are shown. The hourly means have been corrected for the change brought about owing to the variation from the beginning to the end of the month, so as to show the true diurnal period. In the seasonal groupings summer embraces the months of December, January, and February, autumn the three months ending May, winter the three months ending August, and spring the three months ending November. The diurnal range of sunshine and cloud for the months and the year is shown in Table III., and in the same table is included the seasonal percentage amount of rain for four hourly periods. Table IV. gives the monthly and annual values of the principal climatic elements during the period of observation.

The special interest of the data lies in their bearing on the general problems opened up by the results of International Antarctic Meteorological research during the years 1901–1904, and their co-ordination with synchronous data from the stations in the extreme south of South America, in the South Atlantic as represented by results from Cape Pembroke (Falkland Islands), South Georgia, and the South Orkneys, and the east and west coast of Graham Land near the Antarctic Circle, as represented by Nordenskjöld, 1902–1903, and Charcot's 1904 observations respectively. The various points of interest will be gone into later, but meanwhile this condensed summary of the observations may be of interest to other workers in this field.

It is almost unnecessary to mention that New Year Island is situated in the stormy west wind area, and that owing to its strictly insular position temperature is equable and about 1° C. lower than at the adjacent station on the much larger Staten Island (lat. 54° 23′ S., long. 63° 47′ W.), where observations were taken from 1887 to 1895. At the latter station the extremes were greater, there apparently being a tendency to Föhn due to the adjacent mountains. This view is also supported by the smaller cloud amount. Sunshine is relatively abundant on New Year Island, especially in spring, and the rainfall (from a Richard balance pattern gauge, 1·3 m. above the ground) scanty, but with a large number of rain days.

The diurnal range of the elements is small. As at all other southern South American and adjacent sub-Antarctic stations, between 50° and 65° S. lat., the evening maximum of barometric pressure is much higher than that of the morning, except in winter, when there is little difference. Temperature shows a well-marked diurnal range, with a maximum at 13 hours at all seasons, the difference between the coldest and warmest hours varying from 3°·2 C. in summer to 0°·8 C. in winter. Wind velocity is above the daily mean from 10 to 16 hours and below the mean from 18 to 8 hours. The amplitude is greatest, 1·8 m/s in summer, and least, 0·4 m/s in winter. The wind is strongest at all

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TABLE I.—Summary of Meteorological Observations made at New Year Island from March 1902 to December 1905.
Lat. 54° 39′ S., Long. 64° 10′ W.

Month.	Barometric Pressure in mb. at Mean Sea-Level.				Air Temperature in °C. 53 metres above Sea-Level.					Relative Humidity. Mean 24 hours.	Vapour Pressure. Mean 24 hours.	Cloud. (7+10+13+16+19+22).	Sunshine (Jordan).		
	Mean.	Absolute. Highest.	Absolute. Lowest.	Range.	Mean 24 hrs.	Mean Daily. Max.	Mean Daily. Min.	Absolute. Max.	Absolute. Min.				Mean.	% of possible.	Sunless Days.
	mb.	mb.	mb.	mb.	°	°	°	°	°	%	mb.		Hrs.		
January	998·8	1017·6	965·5	52·1	7·95	10·9	5·5	15·1	1·4	82	8·8	8·2	123	24	4
February	997·0	1023·0	963·6	59·4	7·33	10·3	4·8	15·8	0·8	80	8·3	8·0	114	28	3
March	995·8	1025·0	962·6	62·4	6·72	9·1	4·6	13·1	0·2	81	8·0	7·6	118	30	3
April	1000·0	1024·0	971·4	52·6	5·88	7·8	4·2	12·0	−1·0	84	7·9	7·8	84	27	7
May	1000·7	1028·4	966·2	62·2	3·87	5·4	2·3	9·6	−4·1	81	6·7	7·7	54	21	9
June	997·0	1021·4	961·9	59·5	2·14	3·6	0·3	7·8	−5·3	85	6·2	8·2	27	12	16
July	1000·7	1025·1	973·0	52·1	0·79	2·5	−0·1	7·0	−8·4	81	5·4	8·0	39	18	9
August	996·2	1025·0	959·9	65·1	2·35	4·0	0·6	7·3	−4·7	82	6·0	7·6	89	30	5
September	996·8	1024·6	969·4	55·2	3·10	5·3	1·0	8·7	−8·0	79	6·2	7·2	139	40	4
October	998·3	1022·8	969·8	53·0	4·43	7·0	2·1	11·4	−3·3	79	6·7	7·6	168	39	3
November	997·6	1022·7	972·3	50·4	5·58	8·6	2·9	11·8	−2·1	79	7·2	8·0	176	37	3
December	999·1	1025·1	976·7	48·4	6·64	9·8	3·9	14·6	0·7	80	7·9	8·2	154	29	1
Year	998·2	1028·4	959·9	68·5	4·73	7·0	2·7	15·8	−8·4	81	7·1	7·8	1286	29	67

Month.	Precipitation. Rainfall Mean.	Max. fall in 24 hrs.	Rain Days.	Phenomena. Number of Days of: Snow.	Hail.	Fog.	Haze.	Snow on ground.	Thunder Storms.	Gales.	Wind, Velocity and Direction from Hourly Observations 63 metres above Sea-Level. Velocity. Mean.	Velocity. Max.	Direction, % Frequency. N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm	Earth Temperature at Depths of 0·5m.	1·0m.	2·0m.	3·0m.	Sea Temperature at 8 hrs.[2]
	mm.	mm.									m/s.	m/s.										°C.	°C.	°C.	°C.	°C.
January	77	28	21	0	1	5	1	0	2	4	7·0	25·3	11	6	5	3	12	20	20	22	1	9·1	7·3	5·5	5·0	8·5
February	84	22	22	1	2	2	1	0	1	3	8·0	20·0	6	3	3	3	15	24	26	19	1	8·9	7·9	6·2	5·3	8·6
March	68	23	22	2	4	2	2	0	0	7	8·5	24·7	12	4	2	2	10	21	25	24	0	7·3	7·3	6·3	5·6	8·0
April	62	20	18	3	4	4	1	1	0	6	8·0	22·8	10	6	6	2	10	21	26	19	0	5·7	6·5	6·4	5·7	7·1
May	39	12	19	7	4	2	1	4	0	5	9·0	23·2	7	2	1	3	16	27	28	16	0	3·9	5·4	6·1	5·8	5·9
June	51	18	18	12	5	5	0	12	0	6	8·3	22·5	8	4	6	8	15	20	24	14	1	2·1	4·1	5·5	5·8	4·8
July	35	6	18	14	7	1	1	17	0	9	9·1	24·4	6	5	5	7	19	25	21	12	0	1·6	3·1	5·2	5·6	4·5
August	34	10	19	13	6	0	1	10	1	8	9·4	22·8	9	4	2	1	10	20	31	22	1	1·6	2·7	4·8	5·5	5·8
September	32	13	17	7	6	2	2	6	0	10	9·5	22·2	10	5	2	1	10	19	28	25	0	2·9	3·0	4·6	5·3	4·0
October	27	7	17	6	6	2	3	4	1	7	8·7	22·8	9	5	2	1	9	20	27	26	1	4·2	3·8	4·3	5·0	7·5
November	46	16	20	4	3	2	3	1	0	5	7·6	34·0	12	6	4	4	12	18	21	22	1	6·4	4·8	4·5	5·0	5·6
December	49	12	23	1	3	4	4	1	2	3	6·8	20·3	11	7	6	2	12	22	21	18	1	8·1	6·2	4·9	5·0	6·7
Year	604	28	234	70	51	31	20	56	7[1]	73	8·3	34·0	9	5	4	3	12	21	25	20	1	5·2	5·2	5·4	5·4	6·4

[1] Total in 46 months.

[2] Observations begin September 1902.

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TABLE II.—Hourly Departure from Mean of Day at New Year Island for the Seasons and the Year. March 1902 to December 1905.

Hour.	Pressure. (Hundredths of a millibar.)					Temperature.				
	Summer.	Autumn.	Winter.	Spring.	Year.	Summer.	Autumn.	Winter.	Spring.	Year.
						°C.	°C.	°C.	°C.	°C.
1	23	15	−10	4	8	−1·36	−·47	−·20	−·96	−·75
2	7	10	−16	−8	−2	−1·41	−·50	−·23	−1·01	−·79
3	−4	7	−20	−17	−8	−1·43*	−·49	−·24	−1·02*	−·80*
4	−4	4	−23*	−20*	−11	−1·32	−·55	−·24	−1·02*	−·78
5	−3	7	−22	−17	−9	−1·10	−·58*	−·26*	−·91	−·71
6	−3	9	−17	−10	−5	−·64	−·58*	−·23	−·60	−·51
7	−4	11	−7	−6	−2	−·07	−·43	−·20	−·07	−·19
8	−9	13	6	−4	2	·41	−·14	−·18	·37	−·07
9	−15	11	15	−4	2	·85	·25	−·05	·72	·44
10	−20	8	**23**	−8	1	1·22	·63	·25	1·17	·82
11	−24	−2	21	−11	−4	1·40	·86	·49	1·40	1·04
12	−30	−11	11	−17	−12	1·67	·99	·57	1·54	1·19
13	−35*	−23	−6	−20*	−21	**1·81**	**1·06**	**·59**	**1·60**	**1·26**
14	−35*	−32	−15	−20*	−25*	1·75	·97	·47	1·43	1·16
15	−30	−33*	−13	−16	−23	1·53	·72	·28	1·12	·91
16	−23	−29	−3	−8	−16	1·23	·41	·06	·81	·63
17	−13	−20	8	4	−5	·81	·12	−·02	·37	·32
18	−2	−9	16	16	5	·32	−·11	−·08	−·08	·01
19	13	0	20	29	16	−·21	−·19	−·04	−·53	−·24
20	30	8	20	36	23	−·68	−·31	−·08	−·76	−·46
21	43	13	16	**39**	**28**	−·97	−·33	−·11	−·82	−·56
22	**52**	16	9	33	**28**	−1·06	−·33	−·10	−·82	−·58
23	**52**	**17**	−4	24	22	−1·24	−·41	−·21	−·91	−·69
24	42	16	−4	16	18	−1·30	−·46	−·22	−·93	−·73
Range	87	50	46	59	53	3·24	1·64	·85	2·62	2·06

Hour	Wind Velocity. (In tenths m/s.)					Relative Humidity.					Vapour Pressure.
	Summer.	Autumn.	Winter.	Spring.	Year.	Summer.	Autumn.	Winter.	Spring.	Year.	Year.
						%	%	%	%	%	mb.
1	−7*	−1	−1	0	−2	6	1	1	3	3	−·13
2	−7*	−2	0	0	−2	6	2	1	4	3	−·15
3	−6	−1	1	0	−2	6	2	1	4	3	−·15
4	−5	−2	0	0	−2	5	2	1	4	3	−·16*
5	−4	−3	−1	0	−2	5	2	0	3	3	−·11
6	−2	−3	1	2	−1	4	2	1	3	2	−·06
7	−1	−6*	0	0	−2	2	2	1	1	1	·03
8	1	−4	−1	1	−1	0	1	1	0	0	·06
9	2	−3	−1	4	0	−1	0	0	−2	−1	·17
10	6	−2	−1	5	2	−3	−1	0	−4	−2	**·23**
11	6	2	1	6	4	−4	−2	−1	−4	−3	·22
12	10	**5**	2	**9**	**6**	−6	−3	−2*	−5	−4	**·23**
13	10	**5**	2	6	**6**	−7*	−3	−2*	−6*	−5*	·22
14	**11**	4	**3**	5	**6**	−7*	−4*	−1	−5	−4	·19
15	9	2	1	2	3	−5	−2	−1	−4	−3	·15
16	8	2	0	2	3	−5	−2	−1	−3	−3	·06
17	4	1	0	−3	0	−4	−1	0	−2	−2	·02
18	0	−1	0	−4	−1	−2	0	0	0	−1	−·03
19	−3	−1	0	−4	−2	0	0	0	2	0	−·09
20	−4	−1	0	−4	−2	2	1	0	3	1	−·08
21	−6	−2	−1	−6*	−4*	3	1	0	3	2	−·10
22	−6	1	−1	−5	−3	4	1	0	3	2	−·10
23	−6	2	−1	−3	−2	5	1	1	3	3	−·10
24	−7*	2	−1	−2	−2	5	2	1	3	3	−·10
Range	18	11	4	15	10	13	6	3	10	8	·39

Note.—The maximum is shown by heavy type and the minimum by an asterisk (The maximum values for Relative Humidity are too numerous to be indicated.)

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TABLE III.—Hours of Bright Sunshine. Jordan Recorder.

Hour.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
4-5	0·5	...	...	...	...	...	...	...	...	...	1·2	2·2	3·9
5-6	3·0	2·7	0·1	...	...	...	...	...	...	2·3	6·4	4·6	19·1
6-7	6·8	5·2	3·5	...	...	...	...	...	2·0	9·7	12·4	8·5	48·1
7-8	10·0	9·0	9·5	3·4	0·1	...	...	0·9	8·9	13·4	14·4	10·2	79·8
8-9	10·4	8·4	11·7	6·8	2·5	0·1	0·8	6·7	13·1	14·5	15·2	11·3	101·5
9-10	11·4	9·2	11·8	8·9	6·5	2·5	4·9	10·8	14·5	16·0	**16·0**	12·4	124·9
10-11	**11·7**	10·6	11·6	9·8	**9·1**	4·2	6·5	**13·1**	14·5	16·4	15·9	12·4	135·8
11-12	9·1	11·1	10·4	10·2	8·5	**5·4**	6·6	11·8	15·0	**17·6**	15·0	12·7	133·4
12-13	9·3	10·9	11·5	10·3	8·6	5·2	**7·6**	**13·1**	15·2	16·0	14·0	13·4	135·1
13-14	11·0	**11·6**	**12·8**	**12·6**	8·1	**5·4**	7·2	12·8	**15·9**	15·4	14·2	**14·6**	**141·3**
14-15	10·8	10·8	12·7	10·9	7·7	3·7	4·6	11·7	15·4	13·6	12·8	13·8	128·5
15-16	8·8	10·4	10·7	8·5	2·7	0·1	0·5	7·1	13·9	13·1	12·3	10·6	98·7
16-17	8·7	7·8	7·2	3·1	0·1	...	...	1·0	8·7	11·4	11·7	10·5	70·2
17-18	6·3	4·7	4·6	...	...	...	...	...	2·2	7·4	9·3	8·6	43·1
18-19	4·8	1·5	0·2	...	...	...	...	...	...	1·0	4·5	6·8	18·8
19-20	0·8	...	...	...	...	...	...	...	...	...	0·4	1·3	2·5
Total	123·4	113·8	118·3	84·4	53·9	26·6	38·7	89·0	139·3	167·8	175·7	153·8	1284·7

Hour.	Mean Amount of Cloud, 0-10.												
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
7	8·3	8·2	7·8	7·7	8·0	8·3	8·1	8·1	7·7	7·9	7·6	8·3	8·0
10	8·2	8·1	7·9	7·9	8·0	8·9	8·2	7·6	7·6	7·4	8·0	8·3	8·0
13	8·3	7·8	7·6	7·9	8·0	8·4	8·2	7·8	7·2	7·6	8·2	8·2	7·9
16	8·1	7·8	7·6	8·0	7·9	8·4	8·3	7·8	7·3	7·6	8·1	8·4	7·9
19	8·2	8·2	7·7	7·5	7·4	7·6	7·5	7·1	7·3	7·8	8·2	8·0	7·7
22[1]	7·9	7·6	7·1	7·8	6·9	7·7	7·4	7·2	6·0	7·1	7·9	8·1	7·4
Mean	8·2	8·0	7·6	7·8	7·7	8·2	8·0	7·6	7·2	7·6	8·0	8·2	7·8
7, 13, 22 hrs.	8·2	7·9	7·5	7·8	7·6	8·1	7·9	7·7	7·0	7·5	7·9	8·2	7·8

[1] Observations taken at midnight and 4 hours from July 1902 to March 1903 show a rapid clearing of the sky at midnight, when the mean is 0·7 below the mean for the day.

Rainfall. Seasonal Percentage Amount for 4-Hourly Intervals.

Period.	0 to 4 hrs.	4 to 8 hrs.	8 to 12 hrs.	12 to 16 hrs.	16 to 20 hrs.	20 to 24 hrs.
Summer .	**21**	19	18	12*	16	14
Autumn .	14	17	**20**	8*	17	14
Winter .	12*	13	**26**	17	14	18
Spring .	13	18	20	11*	17	**21**
Year . .	16	17	**20**	15*	16	16

Note.—The maximum is shown by heavy type and the minimum by an asterisk.

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TABLE IV.—Mean Monthly and Annual Values of the Principal Climatic Elements at New Year Island, March 1902 to December 1905.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	Mean Pressure in Millibars at Mean Sea-Level.												
1902	...	...	1004·0	995·1	994·0	1002·6	996·0	994·7	1001·5	995·9	996·0	996·1	...
1903	997·9	993·8	987·4	998·7	998·3	996·2	999·0	997·5	996·2	1001·9	997·1	996·6	996·7
1904	999·1	1000·4	992·4	1005·5	1005·4	999·8	1003·6	999·6	994·0	999·0	997·2	1005·6	1000·1
1905	999·5	996·6	999·2	1001·0	1005·0	989·6	1004·4	992.7	995·8	996·6	1000·2	998·2	998·2
	Mean Temperature. °C.												
1902	...	...	6·4	6·8	4·5	1·8	−0·3	1·4	1·3	4·0	4·0	6·7	...
1903	7·6	7·4	6·2	5·7	5·0	2·4	2·2	2·8	3·6	5·0	6·1	6·8	5·1
1904	7·7	7·8	7·0	5·6	2·5	3·2	0·0	3·0	4·0	4·3	6·3	6·5	4·8
1905	8·5	6·8	7·2	5·4	3·6	1·2	1·2	2·2	3·5	4·4	6·0	6·4	4·7
	Sea Temperature at 8 hrs. °C.												
1902	...	...	...	...	...	...	...	..	4·2	4·9	5·6	7·4	...
1903	8·4	8·8	7·9	7·2	6·4	5·2	5·0	4·8	5·1	6·0	6·9	7·4	6·6
1904	8·4	8·6	7·9	6·9	5·1	4·6	4·5	4·9	5·8	6·0	7·3	7·7	6·5
1905	8·8	8·5	8·1	7·2	6·2	4·5	4·0	4·6	4·9	5·6	6·9	7·6	6·4
	Mean Wind Velocity in Metres per Second.												
1902	...	...	8·1	8·5	9·5	8·1	9·8	11·2	9·9	9·7	7·5	6·0	...
1903	6·9	7·9	9·6	8·5	8·7	7·9	9·7	8·9	9·1	7·8	8·3	7·7	8·4
1904	7·1	7·1	9·3	7·1	8·2	7·5	8·3	8·1	7·7	8·4	7·3	6·4	7·7
1905	6·9	9·0	7·0	7·7	9·5	9·7	8·8	9·3	11·4	9·1	7·5	7·1	8·6
	Mean Cloud Amount, 0-10.												
1902	...	...	8·6	7·4	7·1	8·3	8·2	8·3	7·9	7·9	8·4	8·1	...
1903	8·3	8·2	7·4	7·7	7·3	8·2	7·3	7·2	6·5	7·2	7·4	8·2	7·6
1904	8·2	6·9	6·8	8·6	8·2	8·0	8·0	7·4	7·5	7·6	7·9	8·4	7·8
1905	8·0	8·9	7·6	7·4	8·2	8·4	8·4	7·6	7·0	7·6	8·4	8·3	8·0
	Sunshine Hours.												
1902	...	...	71	103	68	39	43	73	110	144	131	141	...
1903	119	110	120	97	68	19	45	86	141	186	199	169	1359
1904	111	152	156	50	37	24	44	91	123	142	183	117	1230
1905	140	79	117	83	42	20	23	106	183	200	189	189	1371
Possible Sunshine.*	515	414	391	312	256	224	215	297	351	431	481·	534	4421
	Rainfall in mm.												
1902	...	...	82	65	37	30	42	38	27	24	66	62	...
1903	59	105	60	75	33	72	26	25	20	35	27	42	579
1904	100	40	48	40	38	42	14	49	67	32	49	51	570
1905	71	106	80	68	48	59	57	26	14	15	40	42	626

* Owing to high ground the total possible sunshine is reduced.

seasons about the hour of highest temperature, when the relative humidity is lowest and the vapour pressure and sunshine at a maximum. The diurnal distribution of rainfall varies with the season of the year, but there is a pronounced minimum (except in winter) during the four hours ended 16 hours.

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In summer the maximum amount of rain is in the four hours preceding sunrise, but in the autumn and winter the maximum—which is well marked—occurs in the four hours ended noon. R. C. MOSSMAN.

EDINBURGH,
28*th July* 1919.

The Climate of the Fiji Islands.

The *Annual Report* of the Department of Agriculture, Fiji, for the year 1917, compiled by Mr. C. H. Knowles, contains a useful summary of the meteorology of the Fiji Archipelago. The data include the average pressure, temperature, rainfall and humidity at three stations, Suva, Levuka and Nasinu, and the average rainfall at numerous others. These data are repeated in Tables I. and II., with the addition of some other figures for Suva. Rainfall stations whose position could not be identified, are omitted. (See map, Fig. 1.)

Suva, on the south-east coast of Viti Levu, is the capital of the islands; Nasinu is the Agricultural Experiment Station in the interior of Viti Levu, while Levuka, on a small island to the eastward, is the old capital.

The islands are within the tropics, and have an average temperature of about 77° F., but they are far enough south to have an appreciable annual range.

The climate is essentially maritime, so that temperatures exceeding 98° F. are unknown, while in normal years 94° is the limit. On the other hand, the nights are warm, the mean daily minimum being as high as 71° F., and the lowest 57° F.

Mean pressure is 1011·8 millibars at Suva, decreasing northwards; it is lowest in January and highest in August, the annual range being 7·0 mb. The barograph shows a well-marked semidiurnal oscillation with maxima about 9 a.m. and 10 p.m., and minima about 3 a.m. and 3 p.m., the second minimum being the more pronounced; the average diurnal range is about three millibars.

The southern winter (May to October) is the season of high pressure, and at this period Fiji falls within the region of South-East Trade Winds. The velocity, however, is small, averaging only six miles per hour. This is the time of relatively less rain, only 42·3 inches falling at Suva in the six months June to November compared with 68·8 inches in the remaining months. Hurricanes are rare or unknown during this period, but heavy thunderstorms occur. During one of these, in August 1906, 26·50 inches were recorded in one day, the next highest total recorded in one day in August over a period of 34 years being only 6·35 inches.

During the southern summer (November to April) pressure is lower, and the Fiji Islands fall more within the belt of equatorial low pressure, consequently winds are more Easterly. The velocity is in general light, but destructive hurricanes occur. In 34 years eighteen gales were recorded at Suva, one in November, the others between December and March. A cyclone on March 24 and 25, 1910, passed across Suva, travelling towards the west-south-west at an average speed of about 10 miles an hour (though the velocity of the wind was estimated to reach 85 m.p.h.). After passing the island of Viti Levu it turned in a north-westerly direction, and decreased in intensity.[1] Although the area of destruction was limited, the wind, and the accompanying tidal wave, caused thousands of pounds of damage, and the deaths of sixteen natives were reported.

The map shows the average distribution of pressure over Fiji, and also the prevailing winds at Suva. It is interesting to note the intimate dependence of

[1] *Colonial Reports, Miscellaneous*, No. 72, "Fiji—Report on the Hurricane of March 1910. London, 1910."

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rainfall on wind in Viti Levu. The figures in circles represent the average annual rainfall in inches, and bring out the steady decrease from the south-east

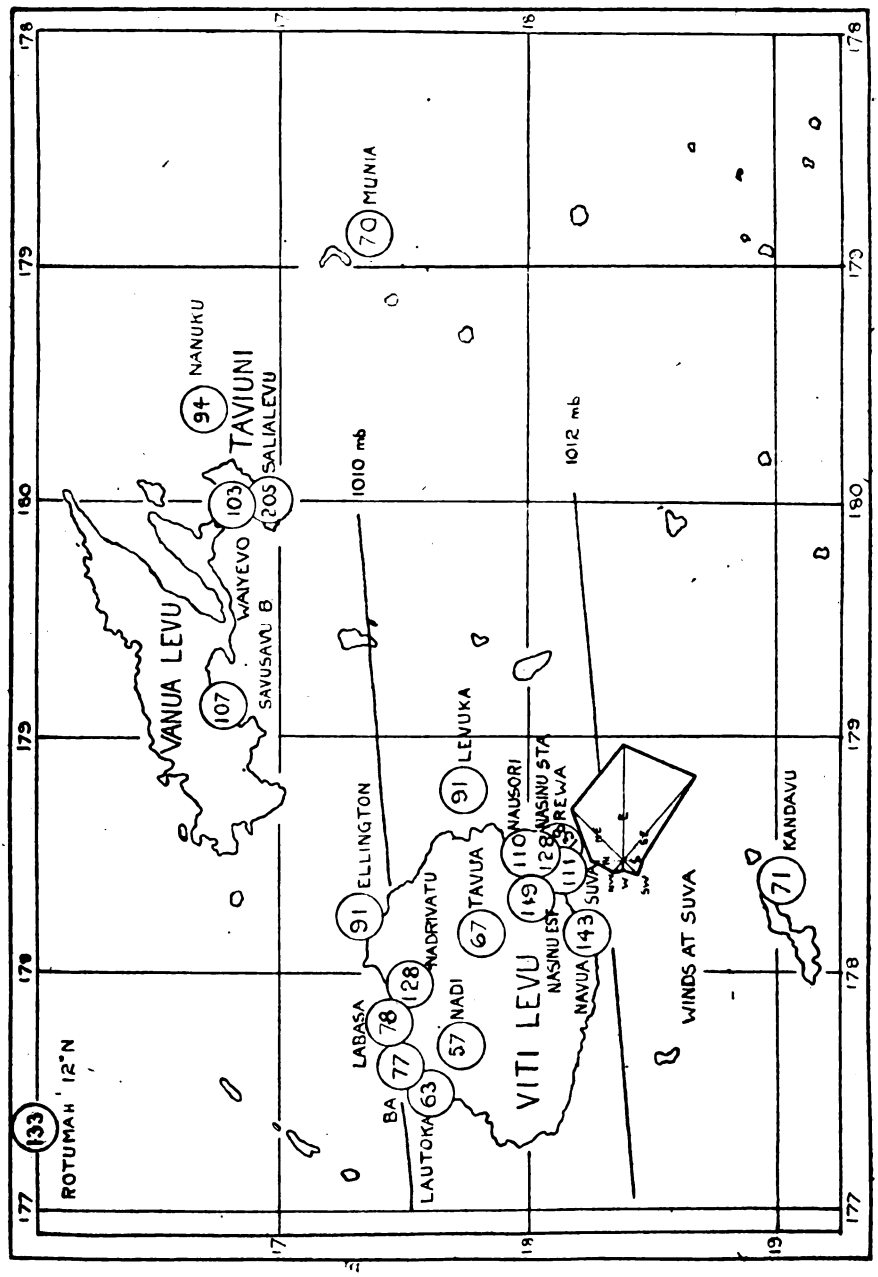

FIG. 1.—Map of Fiji Islands, showing Average Distribution of Pressure and Rainfall over Fiji and Prevailing Winds at Suva.
The figures in circles represent the average annual rainfall in inches.

towards the north-west. This is associated with a corresponding change in the type of vegetation from dense forests in the rainy south-east to open grass land

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TABLE I.—Means and Extremes of Meteorological Observations at Suva, Fiji, 18° 8′ S., 178° 26′ E.

Month.	Mean Pressure at M.S.L.	Temperature.							Relative Humidity at 9 a.m.	Cloudiness, 9 a.m.	Rainfall.			Wind at 9 a.m.									
		Mean.	Mean Daily.		Mean Monthly.		Extreme.				Mean Monthly.	No. of Days.	Max. fall in 24 hrs.	Percentage of Observations from									Mean Force.
			Max.	Min.	Max.	Min.	Max.	Min.						N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	
	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	%	in.		in.	%	%	%	%	%	%	%	%	%	0-12
January .	1007·9	79·9	85·8	74·0	91·3	69·7	95	67	76	56	10·73	23	5·83	10	21	27	24	4	6	2	2	4	2·5
February .	1008·0	80·5	86·5	74·5	91·5	70·8	97	67	78	54	10·10	21	8·23	13	19	29	19	5	3	2	3	7	1·9
March . .	1009·0	80·1	86·0	74·2	91·1	70·8	98	67	80	54	14·82	25	9·55	13	21	25	17	4	7	3	2	8	2·0
April . .	1011·0	78·7	84·3	73·1	89·2	67·5	94	61	79	52	11·25	23	13·18	9	19	28	25	4	5	1	2	7	2·0
May . .	1013·4	76·5	81·8	71·2	87·6	64·9	93	61	80	59	9·91	22	8·76	8	15	25	30	5	6	1	3	7	2·0
June . .	1014·2	74·9	80·3	69·4	85·9	63·6	90	58	80	53	5·86	18	9·05	8	14	25	30	4	3	2	5	8	2·0
July . .	1014·6	73·6	79·2	68·0	85·3	61·5	90	58	79	54	4·53	17	5·95	9	17	23	31	6	3	2	3	6	2·0
August . .	1014·9	73·7	79·2	68·2	85·2	61·9	90	57	79	61	7·82	20	26·50	6	14	28	29	5	7	1	4	6	2·0
September .	1014·6	74·5	80·1	68·9	85·7	62·2	90	57	76	59	6·90	19	5·23	6	17	27	35	4	4	2	2	3	2·6
October .	1013·6	75·9	81·4	70·5	87·2	64·3	93	62	75	59	7·69	19	8·33	5	16	35	30	5	3	1	2	3	2·6
November .	1011·4	77·2	82·8	71·7	87·6	66·6	93	62	75	61	9·51	19	15·91	5	16	35	29	6	4	1	1	3	2·6
December .	1008·8	78·9	84·8	73·1	90·3	68·5	97	65	76	56	11·98	22	12·11	8	14	31	28	5	5	3	3	3	2·6
Year . .	1011·8	77·1	82·7	71·4	93·6	60·2	98	57	78	57	111·10	248	26·50	8	17	28	27	5	5	2	3	5	2·2
No. of years .	31	31	31	31	20	20	34	34	31	34	31	31	34	33									

(The mean pressure is reduced to the mean of 24 hours. The mean temperature is the mean of the mean daily maximum and minimum.

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TABLE II. [illegible] Levuka and Nasinu, and Rainfall at Various Stations.

Month.	Levuka. Temperature. Mean.	Levuka. Temperature. Mean Max.	Levuka. Temperature. Mean Min.	Levuka. Relative Humidity.	Levuka. Rainfall.	Levuka. Rain Days.	Nasinu. Temperature. Mean.	Nasinu. Temperature. Mean Max.	Nasinu. Temperature. Mean Min.	Nasinu. Relative Humidity.	Nasinu. Rainfall.	Nasinu. Rain Days.
	°F.	°F.	°F.	%	in.		°F.	°F.	°F.	%	in.	
January	80·5	85·7	75·3	72	9·73	19	79·1	85·6	72·5	80	11·87	23
February	80·7	85·4	75·9	73	10·17	19	79·1	85·9	72·3	80	12·68	22
March	80·7	86·1	75·4	75	12·97	21	79·1	85·7	72·4	84	17·55	25
April	80·5	85·6	75·3	73	9·40	19	77·5	84·3	70·8	81	8·91	23
May	78·2	83·1	73·3	75	7·37	17	75·3	81·3	69·4	84	14·38	23
June	76·9	81·5	72·2	72	4·75	14	73·3	79·8	66·9	84	7·30	18
July	75·7	80·7	70·8	73	3·49	13	71·7	79·3	64·1	82	5·97	17
August	75·0	80·2	69·8	72	5·88	15	72·1	78·8	65·4	81	7·18	18
September	74·9	79·9	69·9	74	4·65	14	73·1	79·1	67·0	79	7·22	21
October	76·1	80·9	71·4	74	5·60	12	73·9	81·0	66·9	78	8·20	17
November	77·9	83·1	72·6	74	8·44	16	76·1	82·6	69·7	79	12·28	21
December	79·5	84·7	74·2	71	8·87	17	78·1	85·0	71·2	78	14·30	22
Year	78·1	83·1	73·0	73	91·32	196	75·7	82·4	69·1	81	127·84	250
Number of Years	10						10					

Month.	Rainfall at Saliatevu.	Navua.	Naitasiri (Rewa).	Nausori (Rewa).	Nasinu Estate.	Savusavu Bay.	Waiyevo (Taviuni).	Namukulea (Kai).	Labasa.	Ba.	Kandavu.	Munia.	Tavua.	Lautoka.	Nadi.	Nadrivatu.	Rotumah.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
January	15·80	15·06	15·04	11·29	11·21	14·22	12·68	7·37	12·31	12·03	7·65	8·28	9·09	8·68	8·39	22·99	14·39
February	12·90	12·15	15·57	12·13	12·26	9·33	12·88	13·48	13·25	16·61	8·45	7·69	13·59	11·98	10·90	22·78	16·54
March	21·96	16·35	18·49	14·85	16·35	15·08	15·38	12·12	13·63	12·17	8·37	8·75	12·33	10·61	9·11	23·75	13·63
April	14·52	15·24	11·67	10·50	11·13	7·37	9·17	10·63	8·23	7·13	5·76	7·66	5·44	4·49	3·94	8·67	11·03
May	21·82	13·27	11·65	10·26	11·62	9·19	10·37	6·83	4·29	3·62	7·48	5·75	3·74	4·18	3·21	6·70	11·39
June	14·04	7·94	6·80	6·06	6·55	6·08	4·50	5·67	2·03	2·38	2·98	4·19	1·74	2·00	1·95	3·01	7·56
July	13·86	5·58	4·33	4·09	4·90	4·84	1·94	2·14	1·80	1·42	3·38	2·49	1·11	1·56	1·64	2·48	7·06
August	14·05	10·01	8·52	6·67	7·98	4·80	3·72	4·27	1·86	3·10	7·48	3·56	3·68	3·59	3·76	5·96	7·55
September	28·24	8·66	7·99	6·00	6·85	7·66	5·16	4·95	2·75	2·16	4·13	3·55	1·64	1·70	1·79	3·61	10·56
October	16·07	11·01	8·24	6·79	7·46	6·37	6·08	3·04	3·09	3·24	5·56	4·91	2·77	3·03	2·52	4·61	10·05
November	11·44	12·54	11·93	8·50	9·34	8·39	8·72	6·33	4·95	4·43	3·99	5·96	4·42	3·51	3·28	8·06	10·28
December	21·81	14·72	17·72	12·56	13·08	13·23	12·74	16·78	9·66	8·96	5·73	7·11	7·11	7·16	6·93	15·20	12·23
Year	206·51	142·53	137·95	109·70	118·73	106·56	103·34	93·61	77·85	77·25	70·96	69·90	66·66	62·49	57·42	127·82	132·27
Number of Years	4	32	18	22	22	10	10	4	22	22	10	21	10	16	15	16	12

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in the drier north-east. The heaviest average fall, 207 inches, occurs at Salialevu, on the south-east of Taviuni, a small mountainous island east of Vanua-Levu. C. E. Brooks.

OBITUARY.

Colonel W. F. Badgley.

With regret we announce the sudden death of Colonel William Francis Badgley, who passed away in his sleep at St. Heliers, Jersey, on September 1 last, at the advanced age of eighty-one years.

Colonel Badgley was born on the 10th November 1837, and was the son of Hon. William Badgley, judge, of Montreal. He was one of the few survivors of those who took part in quelling the Indian Mutiny in 1857, having landed in India to join the 20th Native Infantry a few days before the Mutiny broke out. He was four years adjutant of the 18th Punjaub Native Infantry, later joining the topographical department, Survey of India, in which he served for many years in Central India, in Madras, and on the Burmese frontier. In 1880 he came home on sick leave and then retired from the service.

Colonel Badgley was elected a Fellow of this Society in 1889, and communicated a paper, "Some Remarks on Dew," early in 1891. His published works include "Heat and other Forces" (1909), and "Electricity and its Sources" (1916).

Mr. W. G. Davis, Hon. Member.

By the death of Mr. Walter Gould Davis, which took place at his birthplace, Danville, Vermont, U.S.A., on April 30, 1919, at the age of 68 years, meteorology has lost one of the few remaining members of the band who laid the foundation and groundwork of weather science in the Southern Hemisphere. Originally trained as a civil engineer, Mr. Davis while still a young man joined his uncle, Dr. Gould, Director of the Cordoba Astronomical Observatory, Argentina, as a junior assistant. Soon after Dr. Gould's retirement in 1884 the meteorological branch, hitherto carried on in conjunction with the astronomical, was constituted a separate service, and Mr. Davis appointed its first Director. From small beginnings the service developed with ever-increasing rapidity, until it became one of the largest and most vigorous weather bureaux south of the line. Its most rapid development dates from about 1902, when the central office was removed from Cordoba to Buenos Aires. The increased telegraphic facilities of the capital enabled Mr. Davis to start a daily weather map, which, with the co-operation of other services, ultimately covered the greater part of the South American continent. A hydrometric section was founded in August 1902, and gauges installed in all the principal rivers of the country from the Santa Cruz in the far south to the Pilcomayo in the north. In 1903 the magnetic branch of the Meteorological Office was organised, with a central observatory at Pilar, near Cordoba, from which magnetic reconnaissances were from time to time initiated. In 1904 Mr. Davis took over from the *Scotia* Antarctic Expedition their sub-Antarctic station on the S. Orkneys, where meteorological and magnetic observations have since been continued without interruption, a relief party being sent down every summer when the seas are ice-free. In August 1907 Mr. Davis also took over a meteorological station established in 1905 on the island of S. Georgia by a whaling Company, observations of a 1st order station being maintained by a paid official of the Oficina Meteorológica Argentina.

In his official character Mr. Davis was respected and beloved, while in private life he was marked by many amiable and endearing qualities. His tactful handling of his staff commanded both their esteem and their loyal support.

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Mr. Davis was a familiar figure at international conferences and congresses, including those of the International Meteorological Committee, of which he was elected a member in 1894. He received from this Society its Honorary Membership in 1898.

Mr. Davis retired from the Argentine service in 1915 after holding office for thirty years. During this period his activity and zeal in the advancement of science in its broadest aspects won the admiration of his colleagues in both hemispheres. R. C. M.

Lieut.-Colonel J. A. McCracken.

Lieut.-Colonel John Alexander McCracken, M.D., whose death occurred at Dublin on December 21, 1918, was born at Newry, Co. Down, on February 4, 1846, and was the son of George McCracken, J.P. He was gazetted Assistant-Surgeon to the 37th North Hampshire Regiment in 1872, promoted Surgeon in 1873, Surgeon-Major, 1883, and Lieut.-Colonel in 1891. He served in the Afghan Campaign, 1878-1880, and at Abassayah during the Sudan Campaign, 1884-1885. For some time he was the Government Meteorological Reporter at St. Anne's, Barbados.

Lieut.-Colonel McCracken was elected a Fellow of this Society on December 18, 1889.

Lieut.-Colonel B. F. E. Keeling, M.C., R.E.

Science in Egypt has suffered a serious loss by the death of Lieut.-Colonel B. F. E. Keeling, M.C., on the 20th of September last, only a few months after he had taken up his new duties as Director-General of the Survey Department.

After taking his degree at Cambridge he went first to the Royal Arsenal, Woolwich, and then to the National Physical Laboratory, where he worked specially in the Metrological Department.

In 1904 he joined the Survey Department of Egypt, and took charge of the geodetic work to which was added in the next year the Helwan Observatory. Although most of his work was concerned with the higher branches of surveying, the comparison of standards of length, etc., he devoted much attention to the meteorological work which was carried on at the Observatory, and to the magnetic observations which were there made. In 1906 he instituted kite and pilot balloon observations at Helwan, and in 1908 undertook an expedition to Mongalla on the Upper Nile to obtain information concerning the upper air conditions prevailing there during the monsoon season. Besides preparing the annual meteorological report of Helwan Observatory for 1904 and several subsequent years, he prepared reports on "The Climate of Abbassia near Cairo," "Evaporation in Egypt," and "Terrestrial Magnetism in North-East Africa."

When the Physical Service was organised as a separate Department to the Survey Department he was placed in charge of it, and did excellent work in its development. During the European War he was employed wholly on survey work, at first with the Ordnance Survey at Southampton, but for most of the time in France, where he was severely wounded. Careful and accurate in all his work, possessed of tireless energy, and fertile in ideas, he took a leading part in the development of scientific work in Egypt, where he will be greatly missed. He had already prepared plans for several important pieces of work in his Department, which will now fall to others to carry out.

He was elected a Fellow of this Society on June 17, 1908, and died at the early age of 39 years. H. G. Lyons.

Sir Henry Weldon, K.C.V.O.

Sir Henry Weldon, K.C.V.O., Clarenceux King-of-Arms, died at his residence, Orchard, Shiplake-on-Thames, on August 25, 1919, at the age of 82 years.

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William Henry Weldon was the only son of William Weldon of Bramley Hall, Yorkshire, and was educated at Harrow. In 1870 he was appointed Rouge Dragon Pursuivant-of-Arms, promoted to be Windsor Herald in 1880, Norroy King-of-Arms in 1894, and Clarenceux King-of-Arms in 1911. In 1902 he was created C.V.O., and received the honour of Knighthood in 1919.

He was elected a Fellow of this Society on December 17, 1913.

REVIEWS.

The Study of the Weather. By E. H. CHAPMAN, M.A., B.Sc., F.R.Met.Soc. Cambridge University Press, 1919. 8vo. Pp. 12 + 131, illus. 3s. 6d. net.

This little book is one of the Cambridge Nature Study Series and is intended for school use. A feature of the book is the large number of exercises to be worked out by the pupils, including out-door observations; *viva voce* questions; individual work to be done at the desk, including the plotting of charts and diagrams; and laboratory questions, some of which involve the construction of simple apparatus. The home-made rain gauge was the *bête noire* of the late Mr. G. J. Symons, and it may be doubted whether he would have contemplated without a shudder the proposal to make a gauge out of an ordinary tin funnel and a measuring-glass graduated in cubic centimetres, however useful the calculation involved might be as an exercise in arithmetic. The book is well illustrated with photographs of clouds and other meteorological phenomena and with weather charts, and seems well adapted to the purpose for which it is intended.

The Application of Meteorology to Gunnery. (Experimental Establishment, Shoeburyness, August 1918.) [By Captain E. M. WEDDERBURN, R.E.] Fo. 1919. Pp. 22.

Captain E. M. Wedderburn has condensed into twenty pages a very interesting pamphlet on "The Application of Meteorology to Gunnery," which he modestly describes as intended to summarise the methods at present in use, but in which he does more than merely state summarised results, for not only does he give tables of factors, constants, etc., but a good deal of the theory by which such tables are obtained, and some examples of their application to particular guns.

The number and extent of the considerations that have now to be taken into account, and about which figures are demanded, are somewhat overwhelming, and there will be many who will derive a little grim amusement from thoughts that this paper may suggest by antithesis as they compare its scope with recollections of the amount of attention paid to meteorology in this connection a few years ago—a situation happily expressed by Lieut.-Col. E. Gold, D.S.O., in the preface, where he writes, "the meteorologist had not only to harvest his crop but had also to market it."

Taking the paper in detail, Part I. deals with "Meteorological Variations in Still Air," and comprises three-quarters of the paper—a significant proportion when one remembers how many people have regarded "Meteorology" as merely the official name for "Wind Corrections." The question of upper air density is first dealt with, starting from Boyle's and Charles' laws and the empirical formula $\log\left(\frac{\rho_o}{\rho}\right) = \frac{h\,(0{\cdot}141)}{10{,}000}$, after which variations from standard density at any height are dealt with in terms of pressure and temperature at the surface, the two being very wisely kept separate.

After some tables of weighting factors, etc., the effect of the variation of gravity and of humidity are discussed, and then, under the heading "Typical Variations from Standard Conditions," a couple of tables show the rate of fall

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of temperature with altitude under different conditions of saturation and dryness. These tables are a little startling in their divergence, and make one wish that examples had been added so as to give the differences in terms of their effect on artillery as well as in degrees Fahrenheit.

The question of rain and cloud is next considered and presents many phases. Simple increase in density due to their presence is dealt with first, and the enquiry then goes on to the direct effect of impact and the loss of momentum suffered by the shell through having to set in motion raindrops that are in its path, and which, comparatively speaking, may be taken as still until affected by the shell. Here it is only possible to get numerical results by making assumptions on such points as size of raindrop and depth of the cushion of denser air in front of the shell, and hence there is a special interest attaching to some notes supplied willingly and unwillingly, by allies and foes, showing the values accepted in some other armies. Evaporation due to the compression of air in front of the shell is also examined, and here too a number of assumptions have to be made to get a numerical result. Mercifully the effect of this particular item works out to so small a quantity that even a large percentage variation in the assumed data would not introduce a serious deviation.

After having dealt with so many various corrections and factors, and proved that they require to be taken into account, it is reassuring to find in the remainder of Part I. that one or two other possible corrections on being examined can be exempted from duty with most present-day guns. However, even this exemption has to be qualified, and there is a distinct hint that it may have to be cancelled if there is a further increase in velocities.

Part II., "Air in Motion—Winds," includes a number of summarised results and factors, but they are avowedly not discussed in the same detail as the matter in Part I., as that would involve repetition of much that has already appeared in the previous memoir on the "Equivalent Constant Wind." The question of vertical currents, which is not considered in that memoir, is discussed here, and attention is called to the present lack of experimental data on this point.

A rather telling example gives a result in which an ascending wind of 5 f/s. produces the same effect as a horizontal following wind of 50 f/s. Such a vertical velocity is not uncommon, but it is hard to measure, and even when measured, at a particular place and altitude, there is a lack of information as to the probability of its being a very local effect, or one that persists over the whole region under consideration.

Part III. on "Sundry Practical Applications" commences with some numerical limits as applied to the question of variations along a trajectory, leading up to some reassuring results on the legitimacy of accepting round numbers in certain cases of air burst ranging or of targets above or below the battery. A pretty point, which might easily be overlooked, is raised in connection with air burst ranging, showing the need of a different meteorological correction according as the ranging is on the correct trajectory or the correct horizontal range—this time I am glad to say with an example to help.

The ground covered is so extensive that Captain Wedderburn has, very wisely, limited the present paper to the mathematical and physical questions that arise between the gunner and the meteorologist, and does not allow the heading "Practical Applications" to draw him into administrative or experimental questions dealing with the methods by which that information can best be transmitted in practice, or how far the computations should be carried out by the meteorologist and how far by the gunner; possibly there is hope that he may write a further paper in which this aspect will be discussed as well.

In the meantime, there is no doubt about the obligation under which Captain Wedderburn has put all concerned by the way he has dealt with the subjects discussed in the present paper. A. J. B.

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† **Furlani, Johannes.**—Beobachtungen über die Beziehungen zwischen der Intensität der chemischen Strahlung der Luftbewegung. Wien, 1919. 8vo. Pp. 39. [0930, 1310]

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* **Eredia, Filippo.**—L' umidità dell' aria in Sicilia. *Catania, Boll. Acc. Gioenia*, **46**, 1919, pp. 7. [1020]

Fontseré, Eduardo, y Cunchillos, Gabriel Campo.—Movimiento de las nubes altas y medias en el zenit de Barcelona. *Barcelona, Mem. R. Acad. Cien.* **15**, 1919, pp. 251–259, pls. 2. [1100]

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† **Hann, J.** *v.*—Schätzung der Bewölkung und Bewölkungsmittel. *Met. Zs., Braunschweig*, **36**, 1919, pp. 276–277. [1075]

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RAIN [1150–1235].

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This is the second of the four parts of M. Angot's monograph on the Rainfall of France. The first part dealing with the north-west was reviewed in vol. 44 of this *Journal*. In the south-west the land relief is much more accentuated and the rainfall contrasts are consequently larger. The annual fall varies from rather more than 80 inches in the Pyrenees, the Cevennes and on the Central Plateau to about 24 at some valley stations in the interior, and to less than 20 inches at a few places on the Mediterranean Coast. October is, on the whole, the wettest month and July the driest.

† **Berne, Département suisse de l'Intérieur, Service des Eaux.**—Table de récapitulation des principaux résultats des observations hydrométriques suisses pour l'année 1916. Berne, 1918. fo. Pp. 83. [1180, 1280]

Christmas, W. D.—Exceptional dryness of October, 1919 [Rothamsted]. *Nature, London*, **104**, 1919, p. 278. [1174]

Close, Sir Charles.—Note on the rainfall at Southampton and London during a period of 57 years (1862 to 1918 inclusive). With special reference to the monthly means. *London, Q. J. R. Meteor. Soc.*, **45**, 1919, pp. 311–314, disc. 314–316. [1150, 1180]

† **Foster, Adolf E.**—Die Niederschläge in den österreichischen Flussgebieten hrsg. vom hydrographischen Zentralbureau im k.k. Ministerium für öffentliche Arbeiten. Beiträge zur Hydrographie Österreichs. Heft 10. Lief. 1–3. Wien, 1913, 1914 and 1918. Pp. 8+220, 2 chts.; 8+190, 8 chts.; 6+272, 2 chts. [Review in: *Met. Zs., Braunschweig*, **36**, 1919, pp. 295–297.] [1180]

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†† **Haeuser, Josef.**—Kurze starke Regenfälle in Bayern, ihre Ergiebigkeit, Dauer, Intensität, Häufigkeit und Ausdehnung. Nach den Beobachtungen der Jahre 1899–1915, unter besonderer Berücksichtigung ihrer Bedeutung und Verwendbarkeit für die Wasserwirtschaft. Fo. 8, 60+242 S. Mit 7 Abbild. im Vorlauf und 245 Abbild. auf 14 Tafeln [Abh. Bayer. Landesstelle für Gewässerkunde (früher Bayer. Hydrotechnisches Bureau)]. München, 1919. [Review in: *Met. Zs., Braunschweig*, **36**, 1919, pp. 297–299, by C. KASSNER.] [1180]

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† **Hann, J. v.**—Der Regenfall zu S. Paul de Loanda, dessen jährliche Periode und Schwankungen von Jahr zu Jahr. *Met. Zs., Braunschweig*, **36**, 1919, pp. 162–163. [1200]

Horton, Robert E.—Some broader aspects of rain intensities in relation to storm sewer design. *Municipal and County Engineering* [*Albany, N. Y.* (?)], June–July, 1919, pp. 12. [1210].

† **Kassner, C.**—Über sehr dichte Regenfälle. *Met. Zs., Braunschweig*, **36**, 1919, pp. 125–132. [1210]

† **Kerner, Fritz v.**—Eine neue Schätzung des Gesamtniederschlages auf dem Meere. *Met. Zs., Braunschweig*, **36**, 1919, pp. 167–168. [1180]

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QUARTERLY JOURNAL

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THE STRUCTURE OF THE ATMOSPHERE WHEN RAIN IS FALLING.

By PROFESSOR VILHELM BJERKNES, Hon.Mem.R.Met.Soc.
(Professor of Geophysics, Geophysical Institute, Bergen.)

[A Lecture delivered before the Royal Meteorological Society on November 7, 1919.]

THE war has placed new problems before meteorologists. This is well known as regards the countries engaged in the war, but the neutral nations also have had their task. They had to keep up their meteorological service without the accustomed help of weather telegrams from the surrounding countries. The question naturally presented itself: should it not be possible to compensate, to some degree at least, for the loss of the foreign observations by completing the observations within their own country, and by making the most intensive use possible of them?

On my proposal an experiment in this direction was tried in Norway in the summer of 1918. The number of observing stations in the southern part of the country was increased from 8 to about 90 (see Fig. 1). This gives a modest approach towards the demand of the theory which I have once formulated thus: the distances between the stations should be space-differentials. The next demand, to make the most intensive possible use of these observations, is to be understood thus: to try so far as possible to penetrate to the true nature of the situations and to the physical reasons for their changes. The time left for a weather forecaster to do this is very limited. But still he has means in his hands to make some advance. It should never be forgotten that the problem of forecasting weather is very simple in principle. The weather changes because the masses of air *move*, and *change their internal state*. All is done if we are able to determine their new positions and the internal state in which they arrive. And if we are not able to solve this problem as a mathematical one, we should never forget the useful hint given by this view of it *to consider the changes of state in connection with the motions.*

To do this practically we first of all draw *the lines of flow.* And we

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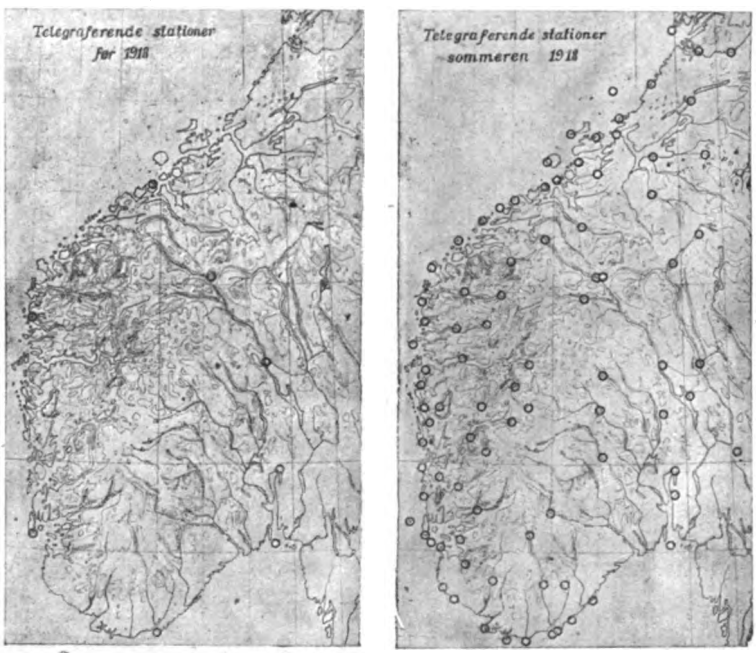
try to draw them with full regard to all observations, not merely to those of the air-motion itself, but to those of temperature, precipitation, humidity, cloudiness, etc. In this way we introduce these lines, so to speak, as *the working hypothesis*, which connects all the phenomena of the chart into an intelligible whole.

I shall not dwell on the practical results which this method has led to—they may be called satisfactory, but not yet brilliant—but merely on the insight which it has given us into some of the secrets of atmospheric phenomena, especially concerning the conditions leading to the formation of rain. The results which I am thus going to present to you are entirely due to the two young forecasters who have had the



a. Until the Summer 1918. *b.* After the Summer 1918.

FIG. 1.—Telegraphic Stations.

practical work in their hands, namely, my son, J. Bjerknes, who had the district of western, and H. Solberg, who had that of eastern, Norway. All results will proceed directly from a series of charts which I am going to show you. These charts contained initially the observations from the above-mentioned 90 Norwegian stations only, but they have been completed later by all available observations, from the climatological stations of the second and the third order, and from all rainfall stations in the three Scandinavian countries.

1. STATIONARY RAIN-STRIPE DUE TO TOPOGRAPHY.

The chart of Fig. 2 gives an example of the formation of rain under the simplest conditions. The wind bears in over the coast, winding

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itself through fjords and valleys, chiefly from west to east. At the same time a broad rain-band lies along the whole of the west coast. It reaches from the outer islands to the dividing watershed, or a little

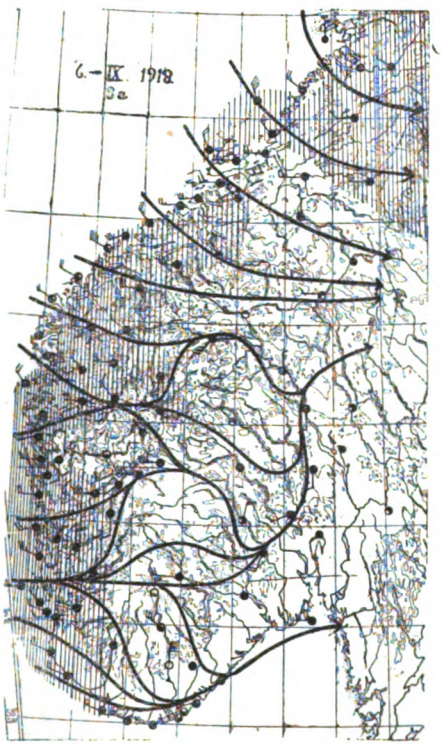

FIG. 2.—Stationary Stripe of Rain due to Wind driven against the Mountains.

beyond this. It is evidently due to the adiabatic cooling of the moist air which is forced to mount the slope of the mountains.

But it is an interesting fact that the moist air does not as a rule come into direct contact with the mountains. The dry air, existing

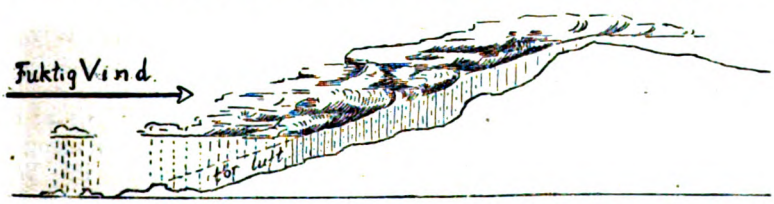

FIG. 3.—Rain by Wind against the Mountains. Vertical section.

here before, cannot escape at once. It is pressed against the mountains by the arriving sea air, fills the valleys and depressions, and forms an even slope up which the sea air flows (Fig. 3). The rain is falling through this stratum of drier air. When this dry stratum is lacking, the clouds are in direct contact with the mountains.

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2. Broad Moving Rain-Stripe.

But our charts show also other types of rain-areas. Fig. 4*a* gives an example of a band at least 800 k. long and 200-400 k. broad, which on September 10, 1918, at 2 p.m., covered the south of Sweden,

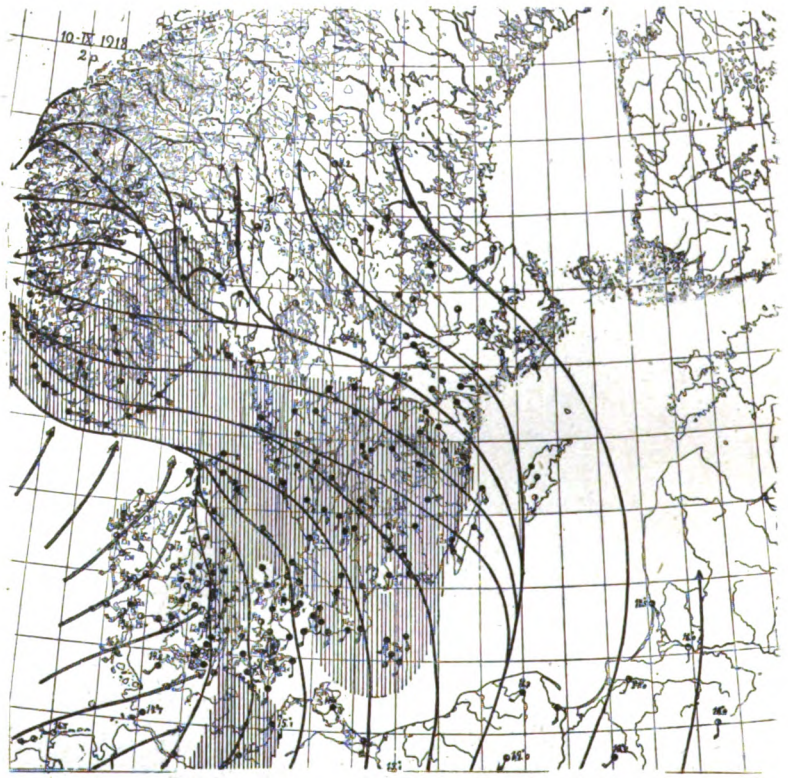

Fig. 4*a*.—Moving Rain-Stripe, broad type.

the Skagerrak, and the southern end of Norway. Six hours later we find the same band displaced about 500 k. toward the north-east (Fig. 4*b*). It has partly been cut off, it is true, by the Norwegian mountains, but in spite of this retains its character of a band.

When we examine the correlated distribution of wind, it is at once apparent that we have to do with *two currents*: one flows along the direction of the band, and another almost normally against it. When we further examine the temperatures, we see that the first current is conveying relatively cold air, the second, air which is as a rule a little warmer. The difference is not so striking in the case before us as in one which I shall show later (Fig. 8*a*, below). But comparing this with a number of similar cases, we shall be in no doubt that we have before us a cold current lying across the course of a warm. The result is as follows: the warm one must, on account of its buoyancy, steer up above the cold, and drop its rain during the ascending motion (Fig. 5).

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Conditions are the same as when the West wind bears in on the Norwegian range of mountains, only the inclined plane of separation is not leaning against immoveable mountains. It yields to the pressure of the warm wind, and the rain-band moves.

The explanation given of this moving area of rain may be tested in

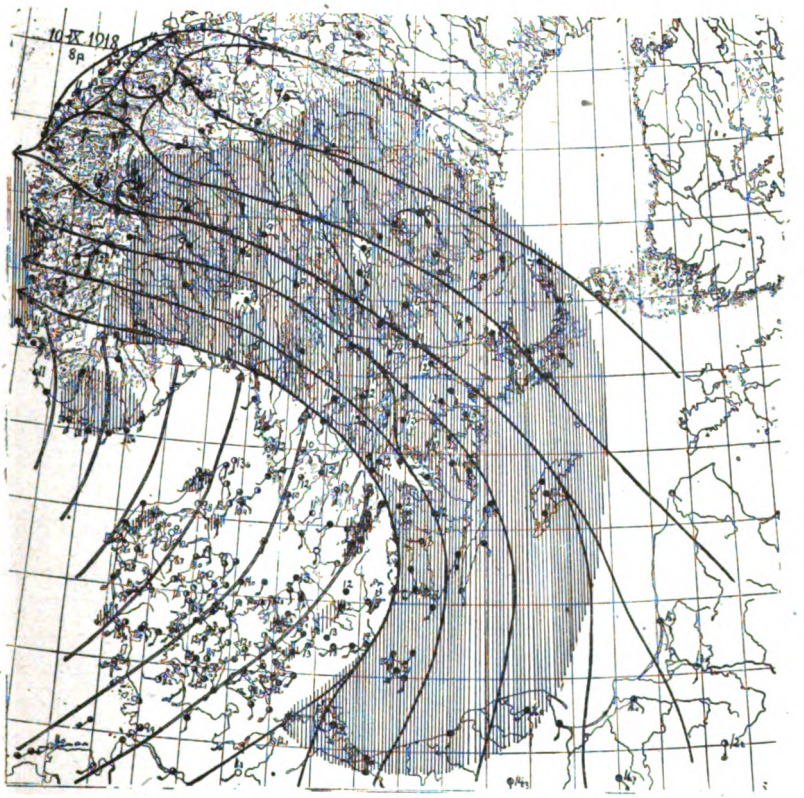

FIG. 4*b*.—Same Rain-Stripe as in Fig. 4*a*, six hours later.

different ways, combining theory with observations. Helmholtz,[1] who introduced the consideration of discontinuous motions in a fluid, has

FIG. 5.—Moving Stripe of Rain, broad type. Vertical section.

[1] Helmholtz, "Über atmosphärische Bewegungen," *Sitz. Ber. K. Pr. Acad. Wissen.*, 1888; *Met. Zeit. Braunschweig*, 1888.

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examined also the conditions for the existence of a surface of discontinuity in the atmosphere. Following up his ideas, Margules[1] has given a very simple formula for calculating the equilibrium-inclination of such a surface as a function of the differences of temperature and velocity. Estimating these differences on our maps we find by Margules'

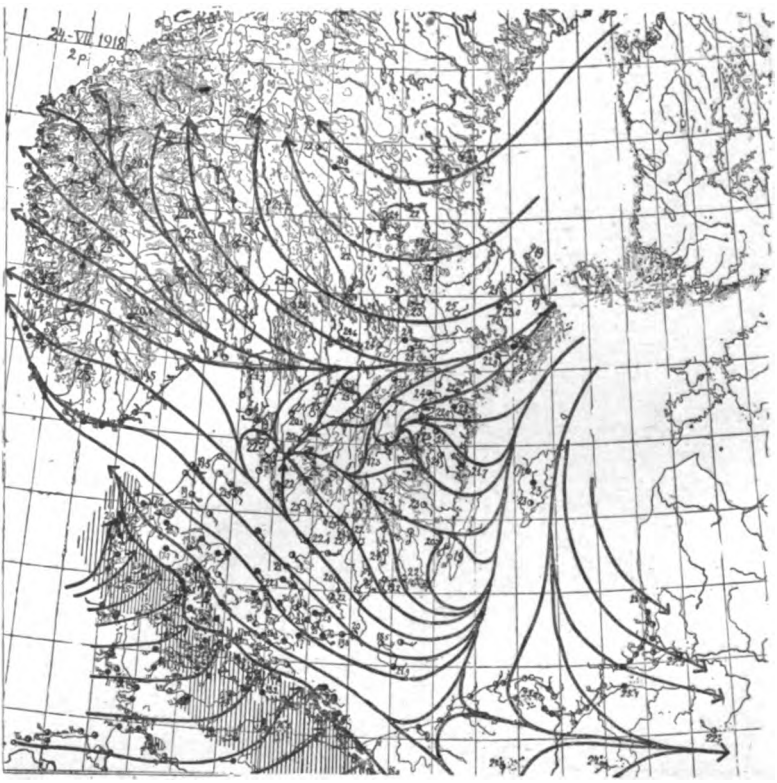

FIG. 6*a*.—Moving Rain-Stripe, narrow type.

formula an inclination, as a rule, of an order of magnitude between 1 in 50 and 1 in 100. As rain is believed to fall from clouds up to a height of 3000 metres, this gives an extension of the rain between 150 and 300 k. in front of the line of convergence, where the warm air begins its ascent of the inclined plane. Higher up, where the warm air has dropped its rain, lighter clouds are formed up to the cirrus-clouds at a height of 8000 to 9000 metres. Supposing them to be situated on the continuation of the inclined plane, we should find them 400 to 600 k. in front of the rain area, which is again in conformity with the observations.

[1] Margules, "Energie der Stürme," *Jahrbuch des K. K. Zentralanstalt für Meteorologie*, 1903, Anhang. English translation, "The Mechanics of the Earth's Atmosphere," by Cleveland Abbe, *Smithsonian Miscellaneous Collections*, vol. 51.

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3. Narrow Moving Rain-Stripes.

But our charts show moving rain-stripes also of another type. Fig. 6*a* and *b* gives an example. It is much narrower than the preceding one, in some places not even more than 100 k. wide. But it moves at

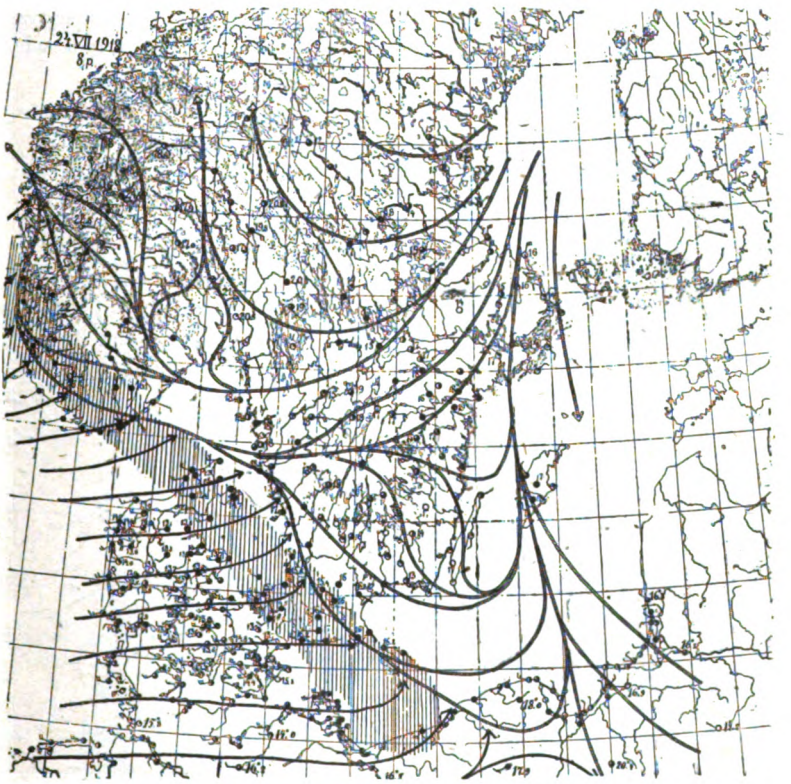

Fig. 6*b*.—Same Rain-Stripe as in Fig. 6*a*, six hours later.

about the same speed, about 500 k. in six hours. The lines of flow show that we have to do with two distinct air-currents. Just as in the preceding case, one is blowing along the direction of the stripe, and one

Fig. 7.—Moving Rain-Stripe, narrow type. Vertical section.

almost normally to it. But there is also a characteristic difference; the boundary line between the two currents lies now at the front of the stripe, not at the back. And at the same time it is seen that the

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temperature is high in front of the stripe, but low in and behind it. Consequently, we have before us a cold current of air which is blowing right across the course of a warm. Then the heavy cold air must flow in under the warm, which is lifted and thus forced to drop its rain through the cold air which lifts it (Fig. 7). The process is in this case a violent one. The broad rain-bands give continuous rain, which starts slowly by single drops and gradually increases to dense rain, which may last from a few hours up to half a day or even a whole

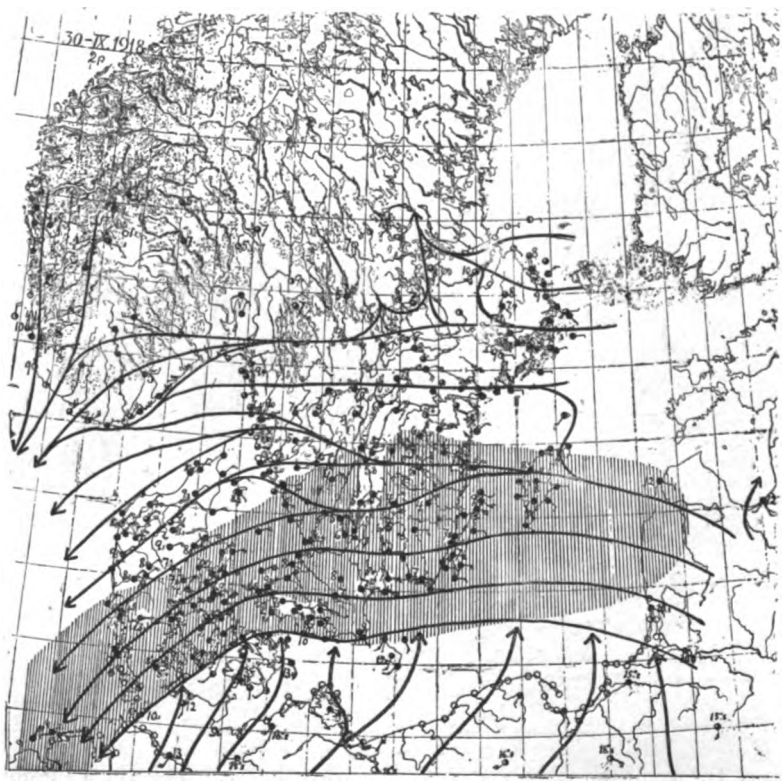

FIG. 8*a*.—Moving Rain-Stripe, broad type.

day. The narrow stripe, on the other hand, gives heavy squalls, which commence suddenly, often accompanied with thunder and violent gusts of wind, first warm and then cold ones. But after a few comparatively heavy showers, we get clear cool weather: it is the well-known *squall-line*.

4. AIR-MOTION AND RAIN IN CYCLONES.

A great number of rain-stripes like these swept over our country in quick succession in the summer of 1918, one of the broad kind, then one of the narrow kind. They followed each other in such a way that we must infer an intimate connection between them. And in two or three fortunate cases the connection was plainly evident on our charts.

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On that of Fig. 8*a* we see the broad rain-stripe, and a very striking rise of temperature behind it. On that of Fig. 8*b* we see that this stripe has advanced towards the north-east, drawing after it a narrow stripe, which comes with cold air. This narrow stripe forms an obtuse angle with the broad one. We have reason to believe it continues down through Germany straight to the Alps. Near the point of connection of the two stripes we have a minimum of pressure. This point is the centre of the cyclone, and the complex rain-band is the rain area of the moving cyclone.

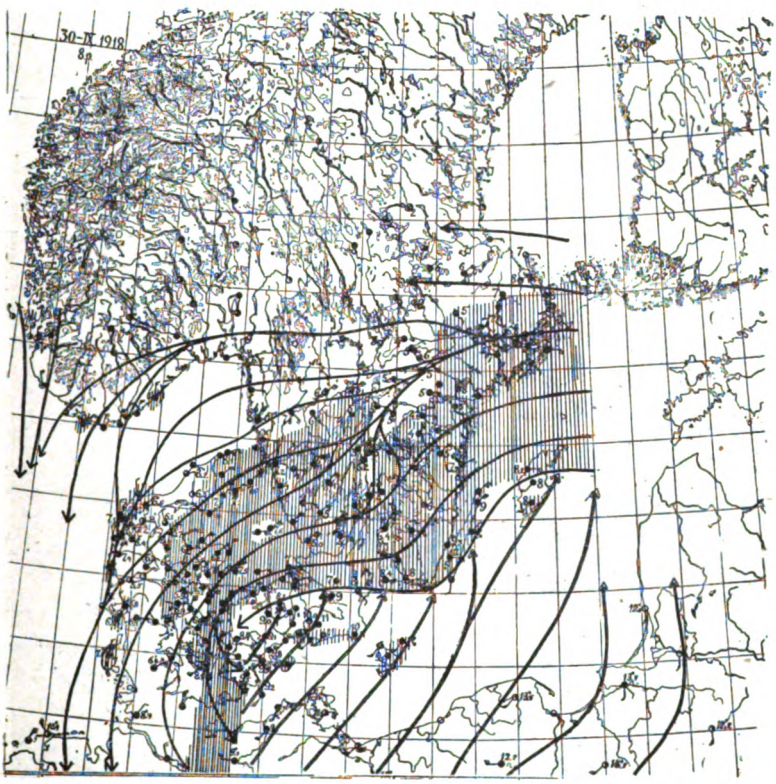

FIG. 8*b*.—Same broad Rain-Stripe as in Fig. 8*a*, twelve hours later, and followed by the narrow stripe.

Fig. 9 gives the schematic picture of a cyclone at which we thus arrive. We have before us a struggle between a warm and a cold air-current. The warm is victorious to the east of the centre. Here it rises up over the cold air, and approaches in this way a step towards its goal, the pole. The cold air, which is pressed hard, escapes to the west, in order suddenly to make a sharp turn towards the south, and attack the warm air in the flank: it penetrates under it as a cold West wind. The centre of the cyclone is thereby displaced to the east, along the southern edge of the broad rain-band. This edge shows thus which way the cyclone will take. We have called it the *steering-line* of the cyclone.

The theory of cyclones to which we have thus been led by the

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inspection of our charts is not new, though it seems to have remained rather unknown, and not to have exerted any influence. The germs of it are contained already in Dove's fantastic theory of the struggle between equatorial and polar currents. In a theoretical paper Helmholtz (*l.c.*) has developed the idea that there is always a tendency towards the formation of a surface of discontinuity between the cold polar air

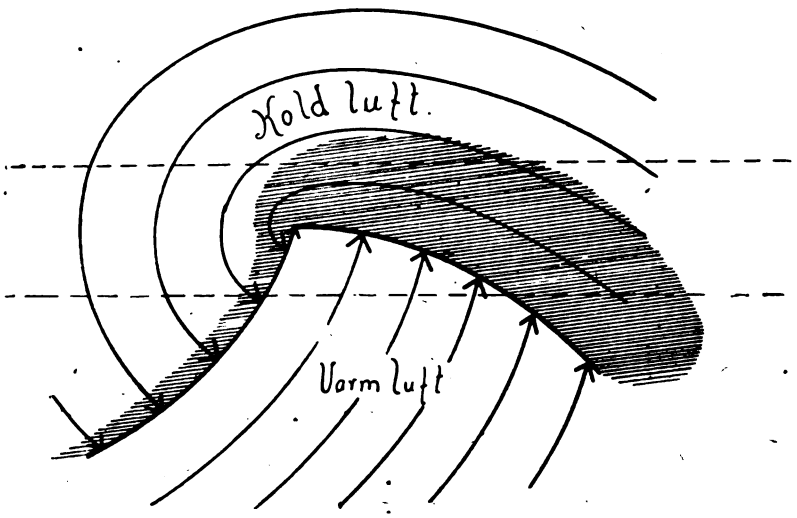

FIG. 9*a*.—Air-Motion and Rain in a Cyclone. Horizontal projection.

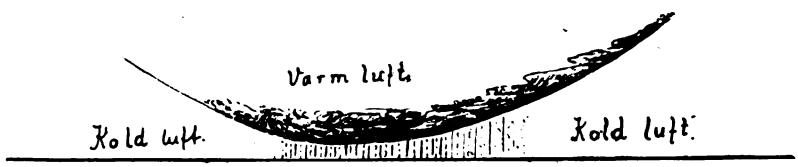

FIG. 9*b*.—Vertical section North of the Cyclonic Centre (along the upper dotted line of Fig. 9*a*).

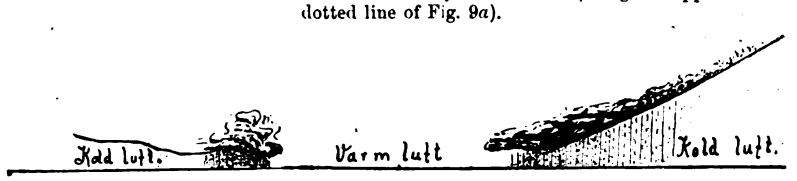

FIG. 9*c*.—Vertical section South of the Cyclonic Centre (along the lower dotted line of Fig. 9*a*).

tending towards the equator and the warm equatorial air tending towards the pole, while the cyclone consists in a kind of "rolling up" of this surface. Similar views have also been taken up in theoretical papers by Brillouin[1] and by Margules (*l.c.*). Finally Sir Napier Shaw has arrived at the same result from the empirical side.[2] By an ingenious use of statistics he has succeeded in accentuating instead of

[1] Brillouin, "Vents contigus et nuages," *Bureau Central Météorologique de France, Mémoires*, 1896.

[2] W. N. Shaw, *Forecasting Weather*, London, 1911, p. 212.

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sweeping out the characteristics of the cyclone. He will permit me to reproduce the very expressive figure (Fig. 10), by which he has given a definite expression to his opposition towards the traditional conception of cyclones, and given a theory which is essentially identical with that derived from the charts before us, and which has been developed now by my son J. Bjerknes.[1]

Before leaving the cyclone it will be of interest to find a measure of the amount of energy involved in the struggle between the two air-currents. We cannot easily estimate the total energy coming into play, but we may estimate a certain definite and probably very small part of it.

The rain-band, stretching from Finland over Sweden and Denmark down to the Alps, has a length of about 2000 k., and an area almost as great as that of Norway. During its motion, which is of moderate railway speed, it has left on the average 10 mm. of rain. To fill this

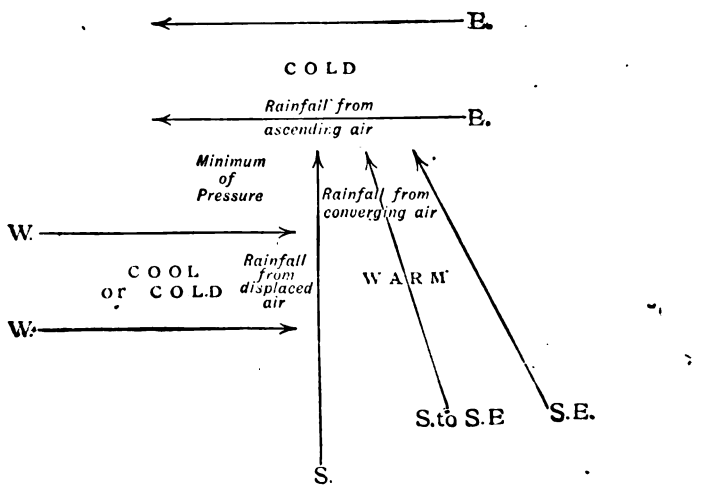

FIG. 10.—Sir Napier Shaw's Diagram representing the constituent parts of a Cyclonic Depression. (Fig. 96, p. 212, *Forecasting Weather*.[2])

measure about 100,000 tons of water have been poured out per second. And if we suppose that this water has fallen from an average height of 1000 metres, we see that the cyclone has carried with it a travelling waterfall of something like 1000 million horse-power, or the power of 15 waterfalls as great as Niagara.

5. APPEARANCE OF THE SKY WHEN A CYCLONE IS PASSING BY.

It is not astonishing that a natural phenomenon of such power may be noticed by different kinds of signs long before its arrival. Such signs are well known to fishermen and sailors. And the view to which we have thus arrived concerning the structure of cyclones is of particular interest in making us understand some of these signs and allowing us to utilise them for forecasting. The two vertical sections of Fig. 9 give the

[1] J. Bjerknes, "On the Structure of Moving Cyclones," *Geofysiske Publikationer*, Kristiania, 1919.

[2] Reproduced by kind permission of Messrs. Constable & Co.

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substratum, showing how the general appearance of the sky changes and the weather develops during the passage of a cyclone.

If we find ourselves north of the cyclonic path (Fig. 9*b*) we have generally a dry and cold East wind. But some thousand metres above our heads we have the current of warm air flowing northwards. And this current is visible from below by the clouds formed in the warm air just above the surface which separates it from the cold air. First we see light cirrus, of a special structure, the first mark that a storm is brewing. In typical cases these cirrus clouds change gradually into a thin milky veil, through which sun and moon are seen as pale discs, often surrounded by halos, which, according to the forecasters of the people, give still stronger evidence that a storm is approaching. The veil gets gradually denser, changing into alto-stratus. Then single raindrops begin to fall, gradually increasing to continuous rain, which by and by gets denser before gradually clearing again; the clearing is followed by a gradual change of the direction of the wind from East to North. At great distances north of the centre only a bank of cirro-stratus is seen to pass slowly by in the south; and at still greater distances up to 1000 k. from the centre the clouds are no more recognised as cirrus, but seen as a narrow dark band near the horizon.

If we are south of the centre (see Fig. 9*c*) the sky initially changes its appearance in the same way as in the preceding case. The precipitation begins in the same gradual manner, and continues as dense rain for a period which may extend from a few hours up to a half or a whole day. But then suddenly the wind turns from SE to S or SW, and the temperature often rises several degrees. The cover of clouds changes from continuous strato-nimbus to fracto-nimbus, above which alto-cumulus may be seen. The rain stops and the weather remains in general fine, though a heavy shower-cloud may now and then pass by. But then, after a period varying from a few hours to a day or two of fine or relatively fine weather, a sudden change comes. As a first warning generally a front of alto-cumulus is seen to approach, from the horizon, soon followed by heavy rain-clouds. The rain begins suddenly with full intensity, in some cases accompanied by thunder, but always with a sudden turning of the wind from SW to NW and often a very striking fall of temperature. But after a few heavy showers the final clearing up follows, provided that the rain does not continue by reason of local causes, as is often the case on the west coast of Norway.

The appearance of the sky in the different parts of a cyclone, at different distances from its centre and in different situations relatively to the steering and squall-lines, is so characteristic, and develops in so typical a way during the passage of the whole system, that it will always be recognised when one has once become acquainted with it. Of course the formation of clouds and rain of local topographical origin may change the picture, but not in general beyond recognition, and these local changes of the picture should be studied carefully at every place. When this is done, observation of the phenomena of the sky will be seen to have an importance equal to the study of the weather chart, especially for short-range forecasts. The time should be past when weather forecasts are made as bureau work in an office from which only narrow strip of the sky is seen.

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6. Local Summer Showers.

We have considered hitherto the major rainfalls: the stationary ones caused by warm and moist air flowing up the slope of a mountain; and the moving ones following the cyclones, and caused by the same warm and moist air, either flowing up a receding wedge, or being lifted by an advancing wedge of cold air. But we have also rain of a far more capricious nature. Everybody is acquainted with the summer days which begin with a fine morning, but as the sun rises the sky becomes cloudy, and in the afternoon suddenly a shower comes, often with thunder. In the evening it clears again, and a bright morning follows. But as the next day advances the events repeat themselves; and in this way it may continue with showers in the afternoon day after day, to the despair of the peasant during the hay-harvest.

These showers seem more mysterious the more closely we try to examine the conditions connected with their appearance. One day may begin equally bright with another, but in one case the sky may remain clear all the day long, while in the other the most violent thunderstorms may break out. And on questioning the inhabitants we get the most confusing information. In one valley these showers are said to come from south, in another from east and so on, and even in different parts of the same valley they may come from completely different directions. There seems to be a complete absence of any law.

We shall see what a series of such days look like on our charts.

Fig. 11 shows the wind at 8 a.m., July 29, 1918. A cyclone has just passed by and left behind it a weak Northerly wind with rather clear sky. But as the sun rises the diurnal winds begin to blow, from the sea to the heated land, from the valleys up along the heated slopes of the mountains. This gives at 2 p.m. the modified distribution of wind represented by the first chart of Fig. 12. In the southern part of the country, where the sea-wind converges from W, S, and E, it has managed to stop the Northerly wind, and a point of convergence is formed above the mountains which separate two of the southern valleys.

Above this point (Evje) the air must ascend. In the ascending air clouds are formed, and before 2 p.m. thunderstorms have raged over the district inside the inner closed area. During the afternoon they spread outwards in all directions, and have reached the outer contour before the night clearing of the sky.

The above-mentioned point of convergence is not the only one, however. Another is seen on the peninsula between the two greatest fjords of the west coast. Here (Voss) we must therefore have an ascending current, and clouds are formed in it, but no rain falls.

In the night, when the solar breezes have ceased, or even turned into weak winds from the opposite direction, we have a general clearing up all over the country. Thus the next morning dawns again bright. But as the sun rises the solar breezes again begin to blow gently, from sea to land, from valley to mountain. We get a very complicated picture of the motion, with a number of points of convergence (Fig. 13). Such a point turns up again near Evje in the southern part of the country, with the same effect as on the day before: showers and

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thunderstorms propagate from it in all directions. A line of convergence is also seen leading from the Skagerrak up to a point of convergence on Filefjeld, and along the whole of this line centres of action for the formation of showers and thunderstorms appear.

But at the same time we have to note the singular fact that the point of convergence at Voss has appeared again, producing only clouds, but no rain, and the same is the case at a new point of convergence formed more to the northward, at Dovre.

The weather clears again over the whole country during the night, as the solar breezes cease, but on the third day the same spectacle repeats

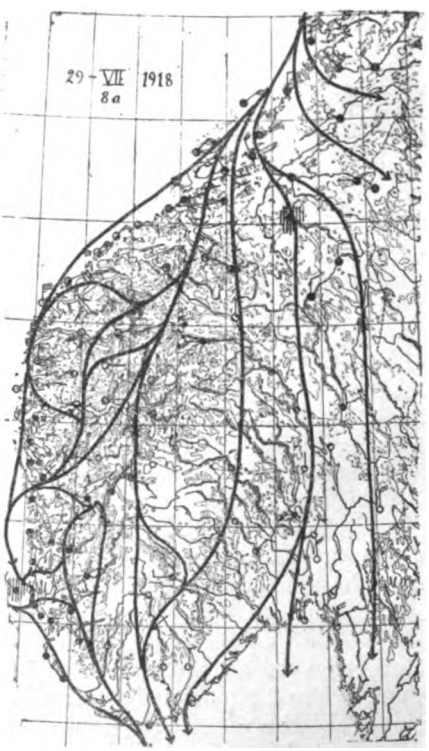

FIG. 11.—First Day of Showers. Air-Motion at 8 a.m.

itself (Fig. 14). The old points of convergence turn up again, and new ones are formed, giving rise to a number of new centres of action, from which showers and thunderstorms originate. It is remarkable that on this day the point of convergence at Dovre, which was inactive the previous day, gives rise to light showers, while the old centre at Voss remains inactive.

On the fourth day it breaks out finally, even at Voss, apparently from several centres at once (Fig. 15). New centres also continue to turn up here and there. At the same time the districts lying under the different centres spread more and more towards each other.

On the fifth day the development continues in the same direction

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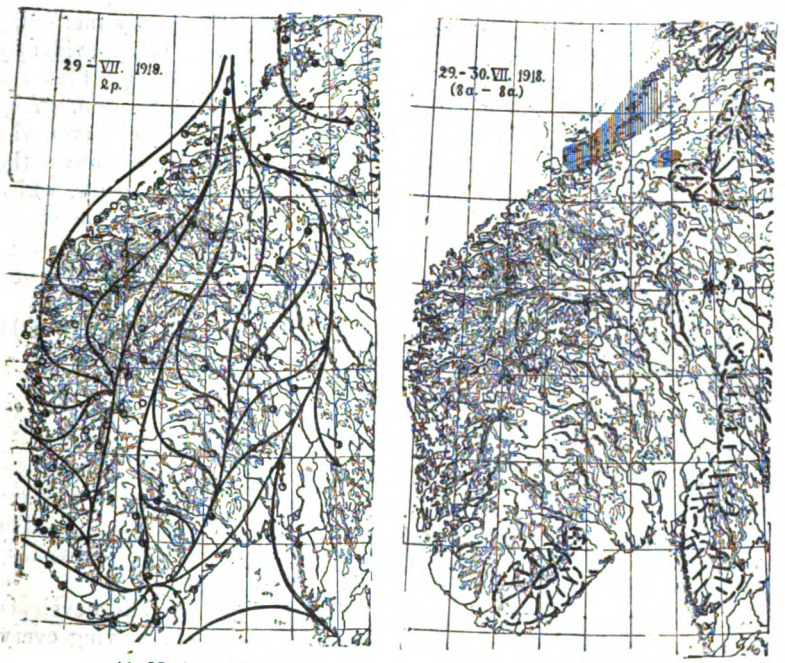
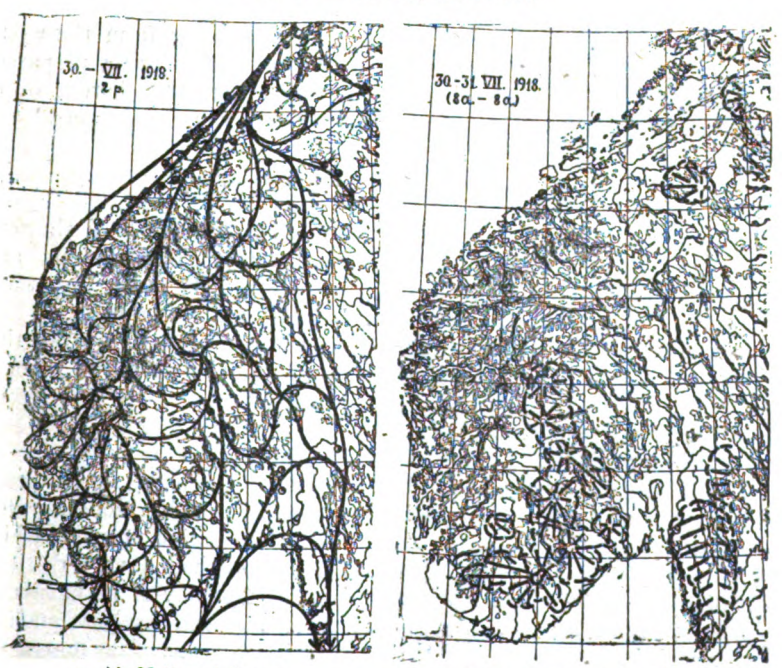


a. Air-Motion at 2 p.m. *b.* Areas swept over by Showers.

FIG. 12.—First Day of Showers.



a. Air-Motion at 2 p.m. *b.* Areas swept over by Showers.

FIG. 13.—Second Day of Showers.

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(Fig. 16). But as the showers thus spread over a continually increasing part of the country certain districts become apparent, which evidently are not easily reached by them. To these districts belong first the mountains which, carrying glaciers, cannot be heated by the sun. Any one who has walked over a glacier in sunshine will have observed the striking phenomenon that the vibrating air flows, not up, but down the slope. Over glaciers we therefore have to expect descending air, which brings clear sky and holds the showers away. On most of the charts a point of divergence will also be apparent over the great glacier of Jostedal (north of Sognefjord), and on several also over the smaller glacier of Folgefonn (north of Hardangerfjord). A similar effect is exerted by the cold surface of the fjords, and of the greater lakes in the interior of the country. Thus on most of the charts a distinct point of divergence is seen over the greatest of the inland lakes, Mjösen.

But now an interesting phenomenon appears: the depressions, which are not reached by the showers in the daytime, get soft rain during the night. These districts are shaded on the map. The reason seems to be obvious. The mountains, which are most strongly heated during the day, are also most strongly cooled during the night. The cooled air sinks back from them into the valleys; the air previously filling these valleys is lifted smoothly, and gives the soft rain.

By the sixth day the centre of action at Dovre has developed strongly (Fig. 17). It draws air from all sides, which, moving everywhere against the slope of the mountains, gives continuous rain all day. A new centre of action has been formed in Sweden, and gives showers over some eastern Norwegian districts, which have hitherto been protected by the lake of Mjösen from showers coming from the west. At the same time a greater change in the weather is being prepared in the south; a dry East wind, which forms the outer border of a cyclone passing by in the south, begins to sweep away the showers.

7. Origin of the Local Showers.

This series of charts shows plainly a relation between local showers and points of convergence of the solar breezes. The showers are formed in the air ascending above these points, from which they then propagate radially in all directions. This radial propagation in connection with the distribution of the centres of action over the country fully explains the apparent contradiction between the reports of the inhabitants in different districts concerning the direction from which the showers come.

But other sides of the question remain obscure.

The points of convergence, with the correlated ascending air-currents, are evidently a necessary, but yet not an entirely sufficient condition for the formation of the showers. Some points are active at once, while others seem to show inertia. Thus at Dovre we had a very distinct point of convergence which was inactive on the first day of its existence in order to enter into activity on the second. And at Voss such a point remained inactive during three days, while on the fourth it turned into an active one.

To see if we can find any law here, we regard the charts in succession.

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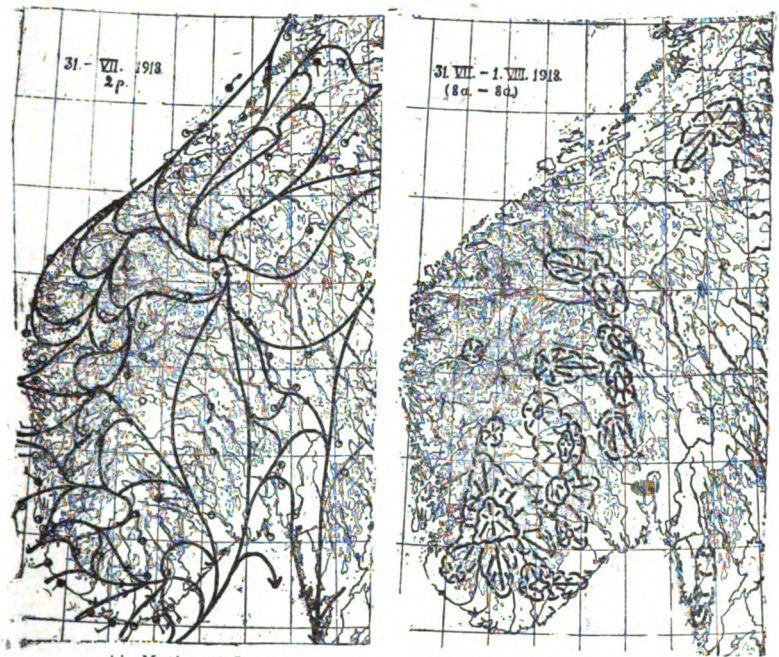
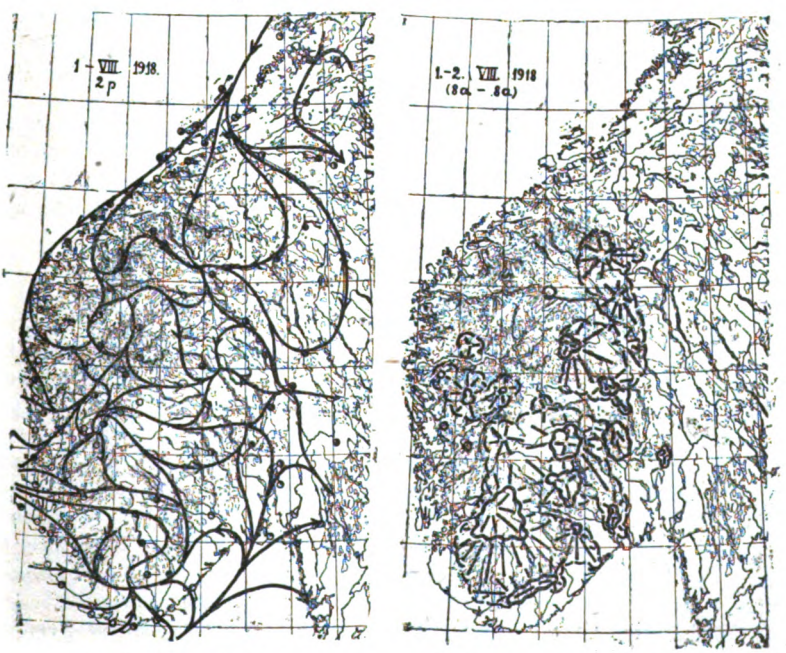


a. Air-Motion at 2 p.m. *b*. Areas swept over by Showers.

FIG. 14.—Third Day of Showers.



a. Air-Motion at 2 p.m. *b*. Areas swept over by Showers.

FIG. 15.—Fourth Day of Showers.

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We see that the first centre of action is situated on a mountain near the coast. And then the activity seems to propagate inwards just as an infection from mountain to mountain, following the relatively straight lines of flow running from south to north up along the broad valleys in eastern Norway. This gives a hint concerning the nature of the infection: it may be humidity conveyed in from the sea by the solar breezes.

The hypothesis can be tested. The inland air contains in the summer about half of 1 per cent of water vapour by weight, and the air above the sea about double the quantity, 1 per cent. By ascending motion the condensation will, according to the initial temperature, begin at heights from 500 to 1000 m. in the case of sea air, but at heights from 1500 to 2000 m. in the case of inland air. This may be sufficient to explain the difference. Now the solar breeze has a speed of 10 to 20 k. an hour. It may thus in a day reach 200 k. or more up along the valleys, and there is hardly any noticeable retrograde motion during the night, except in very shallow layers. It is thus easily explained that the showers are formed on the first day near the southern coast only, on the second as far up as to Filefjeld, and on the third right up to Dovre.

It may appear surprising that the formation of showers travels so slowly in the western districts. But the narrow fjords and valleys are not such convenient canals for conveying the air as the broad eastern valleys. The difference is very well illustrated by the much more curved form of the lines of flow in the western districts. And at Voss, which had to wait so long for the showers, we have the opportunity of a direct test. This was one of the relatively few places where we had a hygrometer. This instrument indicated dry inland air during the three first days when we had a non-active point of convergence. But on the morning of the fourth day it indicated the arrival of air from the sea, and at noon the same day the thunderstorms burst out.

It is interesting to see that the greater part of the showers were fed with water vapour from the Skagerrak, and a relatively smaller part only from the North Sea, while certain quite eastern parts of the country got their showers from centres of action in Sweden, which were fed with water vapour conveyed from the Baltic.

8. General Conditions for the Formation of Rain.

The laws for the formation of local showers, which we have found to hold good in Norway, will certainly show themselves to be true elsewhere, but of course with differences in detail due to the difference in geographical and topographical conditions. Not merely in Norway, but in every country will the formation of these showers depend upon the water vapour conveyed from the sea over the country or the continent by the diurnal winds. This remark may perhaps be of special importance in connection with the theory of the tropical rain periods. Therefore, the results concerning the local showers may be of as general meteorological interest as those concerning the internal structure of cyclones.

At the same time a close relation will be seen to exist between the structural conditions of the atmosphere in the case of the cyclonic rain and of rain falling in local showers. In both cases the rain originates from *new air*. In the case of cyclones this air generally comes from the south,

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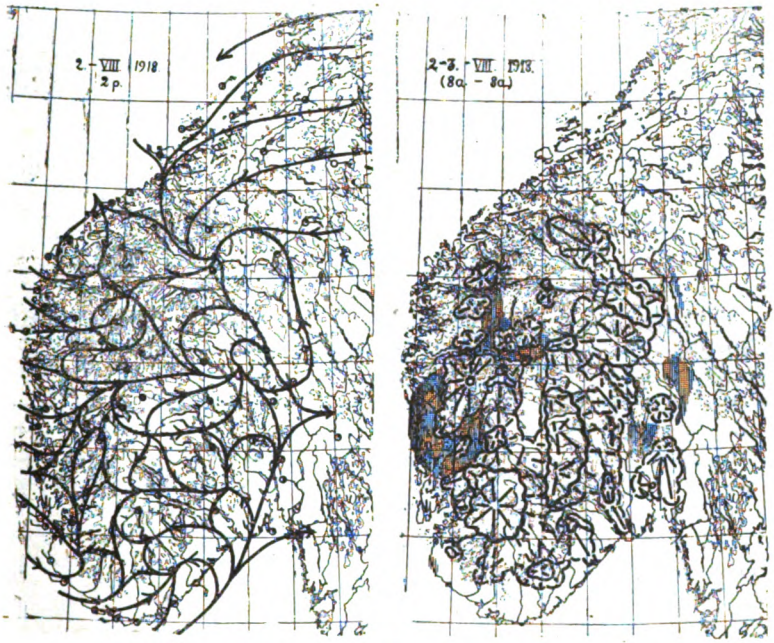
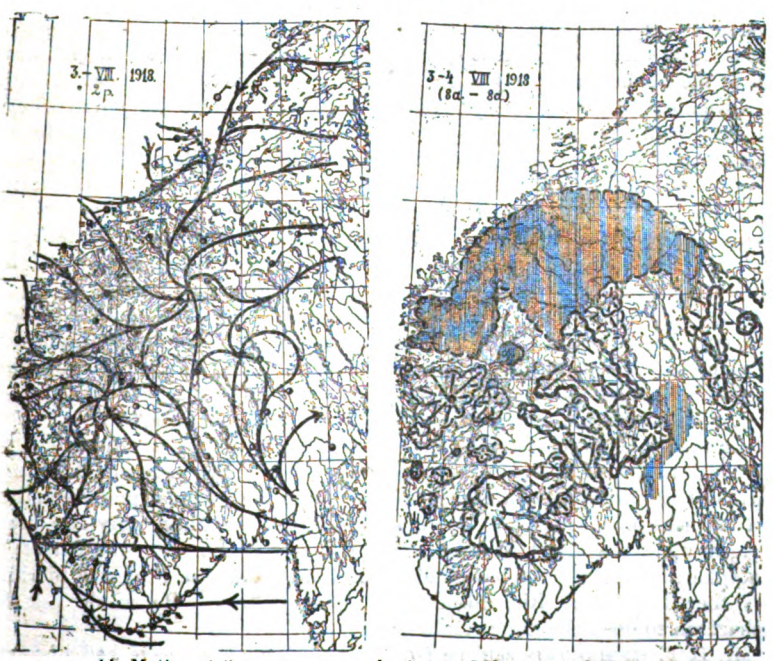


a. Air-Motion at 2 p.m. *b.* Areas swept over by Showers, and Areas of Soft Rain in the Night (shaded).

FIG. 16.—Fifth Day of Showers.



a. Air-Motion at 2 p.m. *b.* Areas of Showers and of Continuous Rain.

FIG. 17.—Sixth Day of Showers.

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in the case of local showers it is propagated into the country from the sea. In both cases this new air is forced to ascend, only the mechanism lifting it is different. In the one case it is forced to ascend by local heating, in the other it meets a wedge of cold air, up which it flows when this wedge is receding, while it is lifted by the cold air when this wedge is advancing.

This view of the conditions under which rain is formed gives a clear indication of the lines to be followed in the attempt to predict it. The main point will be to discover the line of demarcation between the two kinds of air and determine the conditions under which the warm and moist air will have to ascend.

We are trying to follow these lines in the work of forecasting weather in Norway. Conditions are not yet favourable. Telegraphic information from other countries does not yet give us what we require for carrying out the programme satisfactorily.

But apart from practical results, the method has a charm in itself. In its real essence it is an attempt to penetrate every day into the deeper causes of what is going on. This charm keeps awake the enthusiasm of the young scientists during the performance of their work. It is this enthusiasm which has led them to the results which I have had the honour of bringing before you to-day.

DISCUSSION.

Sir NAPIER SHAW, in introducing the lecturer, said that the Society had developed extraordinary activity during the summer and had kept the Officers fully occupied. But it was not due to any spontaneous activity on the part of the Council that they were unable to wait until the Ordinary Meeting on November 19 for an assembly in the Society's inadequate quarters, but to the very fortunate fact that Professor Bjerknes was passing through London from the International Conference at Paris on his way to Bergen, where he was in charge of the Geophysical Institute. He had been engaged on observations of the upper air and was applying these in accordance with the methods set out in his *Dynamic Meteorology and Hydrography*, published about ten years ago. He (Sir Napier) happened to know that Professor Bjerknes had with him a number of charts representing the direct application of this method of detailed observation to forecasting, particularly rainfall; he therefore took the liberty of asking him in the name of the Society to give an exposition of the work which he had accomplished with the aid of his son and he was good enough to consent. He had much pleasure in asking Professor Bjerknes to tell them about "The Structure of the Atmosphere when Rain is falling."

At the close of the Lecture Sir NAPIER SHAW said that although it was not usual to discuss a lecture he felt that Professor Bjerknes would be more gratified than otherwise if a change were made in the habitual practice and the occasion used for discussion. There were, so far as he knew, only two people engaged upon the direct kinematic and thence the dynamic solution of the atmospheric problem by processes of integration. One was Professor Bjerknes, the other Mr. L. F. Richardson working at Benson. He would ask Mr. Richardson to open the discussion.

Mr. L. F. RICHARDSON said he felt deeply honoured to have had his name coupled with that of Professor Bjerknes. Professor Bjerknes in his very

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interesting lecture had presented information from a wealth of meteorological stations such as was not to be found in this country. Formerly cyclones were supposed to be due to warm damp air rising. Next, the observations with meteorographs, which are associated in this country with the name of Mr. W. H. Dines, showed that the air in a cyclone up to about 9 k. was colder than the average ; and so the old view was abandoned. Now Professor Bjerknes showed a picture of a typical cyclone, rather suggestive of a dog chasing its tail—the dog being the cold air, and the tail the warm air. Was average temperature in cyclones low, for the reason that the dog was larger than the tail? The drawing of the very detailed wind maps must have been a task involving great judgment and skill, for he noticed that the black lines of flow did not always fit in with the wind arrows.

Mr. M. A. GIBLETT said that in studying the structure of depressions as revealed by observations of upper winds obtained by means of pilot balloons, he had found two cases of an inclined surface of discontinuity between two wind currents. In the first case, April 3, 1918, a depression was centred off the south-west of the British Isles and moving eastwards. Pilot balloon ascents in Anglesey and at Barrow showed that the Easterly wind current in the north-east point of the depression was bounded above by a surface sloping upwards towards the south-west at an angle of about 1° to the horizontal, slightly greater, but of the same order as the average angle of inclination found by Professor Bjerknes and supported by the formulae of Margules, of the "steering surface" or surface of separation between the warm South-westerly current of a depression and the colder and more Easterly current over which it rises. The two surfaces rise in opposite directions, but it was not determined on which side of the stratosphere they would meet if they continued upwards at the same angle of inclination. In the other case, March 11, 1918, a depression was centred to the south of Iceland and moving north-eastwards. It extended over the whole of the British Isles. Here the Southerly wind current over the south-east of England and north-east of France was found to be bounded above by a surface inclined upwards towards the north-west at an angle of about 0°·8 —again of the same order. It was confirmed by a number of simultaneous pilot balloon ascents at places in south-east England and north-east France.

Sir NAPIER SHAW said that Professor Bjerknes had again brought to their attention the method of arriving at the structure of a cyclone through a detailed study of kinematics in the first place leading to dynamics later on. The essential feature of the cyclone which Professor Bjerknes had shown was that it comprised two lines of discontinuity, the line which Professor Bjerknes called the "steering line" and the one he called the "squall line." Over the rest of the area there was continuity. There was reason to believe that the discontinuities introduced at the surface were peculiar, to a certain extent, to the surface. If certain generalisations of Mr. W. H. Dines could be trusted there should be no discontinuities in the upper air. If there were, the changes of temperature would not correspond in direction with the simultaneous changes of pressure. It was quite possible that all these phenomena of discontinuity which represent the conditions of rainfall were due to the surface, and that higher up the cyclone might have much more symmetry of shape and character. It might find itself considerably hampered in the course of its proceedings by having areas of irregular temperatures to deal with at the surface. Above the level of two kilometres the temperature apparently followed the pressure—if the pressure went down the temperature went down ; but with changes of pressure at the surface the air might be warmer or colder according to its past history during an undefined period. In the very interesting stereoscopic view of a cyclone which Professor Bjerknes had passed round there was shown a steady current from the west above the layers where convection was taking

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place. He believed Professor Bjerknes regarded that steady current as more or less belonging to the stratosphere. Captain C. K. M. Douglas also thought the discontinuity went as far as the stratosphere. There was plenty of opportunity now when so many people were flying up within touch of the stratosphere of finding out how high these discontinuities extended. Convection was now regarded as the cause of rainfall and had taken on three different forms—(1) air rising like a big bubble and producing cumulus and cumulo-nimbus clouds; (2) air going upwards as a current, moving up a slope over the cold air; (3) cold air going under the warm air and pushing the warm air up. So that now instead of regarding convection as warm air rising through cold there were three ideas to be kept in mind, each representing specific conditions. For that reason it was very desirable that meteorologists should associate with them their colleagues of the physical laboratories and the mathematical classes in the universities. He hoped that Professor Bjerknes' contribution would enable meteorologists to appeal to them to calculate that interesting angle of slope which Mr. Giblett had verified in such an astonishing manner by the observations that had come in the day's map. Sir Napier expressed the thanks of the Fellows to Professor Bjerknes for his lecture and hoped it would not be long until he came again.

Professor BJERKNES in reply to Mr. Richardson said that from a consideration of the statistics he thought the reason for the cold temperature of a cyclone was because the dog was greater than the tail. It was quite true that the lines of flow did not always fall on the arrows. There was a certain average used, and less importance was attributed to the weaker arrows than to the stronger. Sometimes it was convenient to ignore an arrow. He thought that Mr. Giblett's information was very interesting. To a certain extent he knew his picture was a very idealistic one and that there were all kinds of blemishes in it.

Mr. CARLE SALTER wrote that he much regretted being obliged to leave before having any opportunity of taking part in the discussion on Professor Bjerknes' extremely fascinating lecture. He thought that Professor Bjerknes was to be congratulated not only upon the new light which his work and that of his pupils was throwing on the dynamical structure of the atmosphere, but upon his stimulating methods of exposition. In a great measure Dr. Mill's work on the distribution of rainfall in the British Isles was complementary to that now described. Dr. Mill had started from the standpoint of the geographical distribution of rainfall and had paid attention also to the variations of intensity in relation to the different types of distribution. He (Mr. Salter) ventured to hope that Professor Bjerknes would extend his range of observations, if he had not already done so, to include a closer attention to the amount and intensity of rain in the differing circumstances which give rise to it. He believed that this would not fail to throw more light on some obscure points.

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PIONEERS IN THE SCIENCE OF WEATHER.

By Sir NAPIER SHAW, LL.D., Sc.D., F.R.S., President.

[An Address delivered before the Royal Meteorological Society, January 21, 1920.]

"Let us now praise famous men—and our fathers—who begat us." It is a time-honoured custom in the collegiate institutions which owe their foundation and maintenance to the liberality and public spirit of far-sighted men to set apart one day in the year for the commemoration of their founders and benefactors. The words which I have quoted form the first sentence of the special lesson of the Commemoration Service. The motive which prompts a wealthy man to entrust the use of his wealth during his life-time, or after his death, to a society formed for certain definite purposes, in preference to retaining the administration of it for those same purposes in his own hands or those of his natural successors, is a subject which may well be worth pondering in these days of uncertainty and unrest.

The Royal Meteorological Society is not one of the institutions which depends for its maintenance to any large extent upon the pecuniary gifts of pious founders and prominent benefactors. If we were called upon to recite the names of those who have endowed the Society with various gifts and estates we should not find the recitation take up much of our time. Yet there are in the circumstances of to-day certain notable features which justify me in asking you on this anniversary to pause for a while in the almost breathless pursuit of new knowledge of the upper and the lower air to recall the memories of some of the men through whom we have obtained the heritage, not of wealth indeed but of knowledge, which is ours.

The special features in the circumstances of the time which I have in mind are the changes in the relation of the State to the practice of meteorology which have been consummated during the past year by the incorporation of the work of the British Rainfall Organization with that of the Meteorological Office. Up to this year the United Kingdom of Great Britain and Ireland was unique among the nations of the earth in making no official provision for compiling information about its rainfall. By the resolutions of the International Congresses of Vienna in 1874, and of Rome in 1879, the Government of this country accepted the duty of contributing its share to the knowledge of the meteorology of the land areas of the globe, with its various orders of stations, just as by its participation in the Conference of Brussels in 1853 it had previously accepted the duty of contributing its share to the general knowledge of the meteorology of the oceans. But it has taken forty years for those resolutions to find embodiment in a unified system for the collection of information for the daily weather service, the climatology, and the rainfall of the British Isles. It is a subject of some personal interest to me because those forty years happen to cover the period of my association in various forms with the Meteorological Office.

The reasons for the long postponement in this country of what is elsewhere a primary duty of the state are twofold. First the beneficence of nature in all the realities of weather in these islands is so nearly

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unbounded, or perhaps I should say that the malevolence of nature is providentially kept within such narrow limits, that there is no rankling grievance against the elements so deep as to make the weather an element of the political situation. It is only economic, and only that in a degree which requires the ingenuity and patience of your new president to disclose. In a general election very few votes are cast in support of or in opposition to the Government policy with regard to the weather. And the second reason, which seems at first sight, but only at first sight, to contradict the first, is that in this country there have always been pioneers willing to do for the public what the public ought to be prepared to do for itself, and often doing it so efficiently that the representatives of the public were justified in considering it not only cheaper (for them) but also wiser not to interfere. So we have had the advantage of many private organisations for doing work which in other countries was carried out at the public expense. Mr. Glaisher's climatological organisation, based on the Greenwich Observatory, supplied the Registrar-General of Births, Deaths, and Marriages in England and Wales with the climatological data necessary for his vital statistics; the corresponding organisation of the Scottish Meteorological Society under Dr. Buchan did the same for Scotland; only the Registrar-General for Ireland within my memory relied for his meteorological information upon the official organisation, and that in its turn depended upon the voluntary contributions of the country gentry of Ireland who held so prominent a place in the records of observational science. It was upon the same sources in conjunction with the climatological organisation of this Society that the Meteorological Office relied for the national contribution to the climatology of the globe, and especially we must name the British Rainfall Organization, formed nearly sixty years ago by Mr. G. J. Symons, which, aided by many local organisations for counties and districts, was developed so extensively and successfully by its founder and subsequently by Dr. H. R. Mill that it has achieved a prominent position among the organisations of the world for the study of rainfall.

These agencies are now all co-ordinated in the Meteorological Office, and at the same time after fifty-two years of independence of government, except for a fixed annual "grant in aid" and the regular audit of its accounts, the Meteorological Office finds itself, by a decision of the War Cabinet, "attached" to the Air Ministry, and is once more responsible to a Government department. The details of the scheme of attachment have not yet been made public, but whatever they may prove to be there can be no doubt that the year 1919 will be a most important one in the history of meteorology in this country.

Regarding the events with what detachment I am still entitled to, I think we may view the history of the last sixty years as the gradual manifestation of the dominance in public estimation of the daily weather service begun by FitzRoy in a very tentative way on September 3, 1860. Even in FitzRoy's time it tended to overshadow marine meteorology, its partner in the Office at that time, and now there is some danger that climatology and rainfall, the study of the upper air, and perhaps also atmospheric pollution, may be judged by the public according to their usefulness in forecasting.

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The Society is left with the duty of fostering the development of the science of meteorology in its various forms. I do not anticipate that its duties will be on that account less arduous or less interesting, but they will certainly be dependent upon the generosity of men of public spirit not in regard to wealth alone, though that is a consideration, but in regard to ideas, and contributions of an intellectual kind, towards forming the science of weather which has the signs of becoming and may soon become an organised system. Early in the nineteenth century J. F. Daniell wrote on meteorology and explained to his readers that he offered a collection of essays because the meteorology of that time did not admit of any other treatment. The science is still for many people a collection of essays, but perhaps the Daily Weather Map, which has had such potent effects on meteorological institutions, may in time by its contributions to our knowledge of detail enable us to achieve the unity of the science itself. To that end the community of meteorologists has always endeavoured to contribute: it is the avowed object of the Society and the object not less evident of the meteorologists who preceded its foundation.

Looking back on the history of meteorology in this country or in any other we find three well-marked periods, the first before the invention of the barometer and thermometer, the second from the invention of the barometer to the invention of the weather map, and the third from the invention of the weather map to the present time. The last period practically coincides with the duration of the history of the Society, which is written for those who read in its *Journals*, and I propose this evening briefly to commemorate the names of those early pioneers belonging to the middle period who endowed the science with those ideas which made the foundation of the Society possible and entitled the subject to the name of a science.[1]

The barometer was invented by Torricelli in 1643; thermometers with the graduations now used were not introduced until much later, the Fahrenheit scale in 1714 and the Centigrade in 1743. Instruments of the same kind of construction but with a variety of scales were employed, and, though Capper in his book on the winds (1801) gives temperatures in Fahrenheit for the years 1747 and 1748 at Aleppo, even so late as 1781 the readings of the instrument used by his great grandfather in the diary of observations which Sir Henry Lambert showed us at our last meeting were in a conventional scale in which 17½ meant extreme heat and 5 extreme cold.

The first of the pioneers whom I will name is **Robert Boyle**, who was born at Lismore Castle, County Cork, in 1627, the seventh son and fourteenth child of Richard Boyle, first Earl of Cork; at eight years of age he went to Eton for nearly four years, and, after reading with private tutors, was sent to Geneva for accomplishments, visited Florence and studied the work of Galileo. He was unable to return on account of financial embarrassments until 1644. On the death of his father he succeeded to the manor of Stalbridge. He took no part in the stormy politics of the time, but joined the "Invisible" club and devoted himself

[1] For the greater number of the facts and dates which are included in this review, I am indebted to the *Dictionary of National Biography*, and desire here to express my obligations to that great work.

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to experimental philosophy. In 1654 he settled in Oxford, at that time the centre of an association of philosophers which some years later developed into the Royal Society of London. There he had a laboratory and made his famous experiments "touching the spring of air," produced the compressing air-pump, and gave the law of relation of volume to pressure which is known by his name, the first step in the dynamics of the atmosphere. The first English thermometer based upon the expansion of a liquid in hermetically sealed glass was also made under his direction. He left Oxford for London in 1668 and thereafter lived with his sister Lady Ranelagh in Pall Mall. He devoted his time to the Royal Society, not then in Burlington House, and to religious enterprises until his death in 1691.

Boyle had with him as his laboratory assistant at Oxford the next of our worthies, **Robert Hooke**, who was born at Freshwater, Isle of Wight, in **1635**, his father being minister of the parish. He was educated at Westminster School, and as a chorister at Christ Church, Oxford. He subsequently became curator of experiments at the Royal Society, and Professor at Gresham College. He was an extremely ingenious experimenter. "He invented thirty several ways of flying." We owe to him not only Hooke's law "ut tensio sic vis," but also the invention of the wheel barometer, and with that I think the selection of the legends "Rain," "Change," "Fair," etc., which formed the basis of popular ideas of scientific meteorology for two hundred years and are still engraved on wheel barometers even to the present day. They have been used in many localities irrespective of latitude or height above sea-level. FitzRoy succeeded in introducing a modification of the legend for cistern barometers, but Hooke's legends can still be seen in Britain for change at 29·5 inches and in France at 760 millimetres. Hooke also invented the double barometer and a marine barometer described in *Phil. Trans.* vol. 22, p. 791. He died in 1703.

The next of our famous men, **William Dampier**, sailor and buccaneer, was a pioneer in the other side of meteorology, namely, the collection of information for a description of the distribution of the wind over the oceans, for which the Meteorological Office was founded. He was born in **1652** near Yeovil, the son of a tenant farmer, and after many adventures died in London in 1715. His first buccaneering expedition was in 1679 to the Isthmus of Darien, when he got as far south as Juan Fernandez, getting or building a ship on the other side, as so many travellers in the Spanish Main seem to have done. Later on Alexander Selkirk, the prototype of Robinson Crusoe, was one of his men. In 1683 he was out again to Chili, Peru, and Mexico. Not being very popular with his men he was put ashore on the Nicobar Islands in 1688, but managed to find his way home by 1691, and in 1697 published his remarkable book *A Voyage round the World*, about which all that need be said here is that the discourse on the winds is so excellent that Captain Basil Hall, known as the climber of the Peak of Teneriffe, writing to J. F. Daniell, speaks of Dampier's book as the authority on details of winds though it had then been published more than a hundred years. Here is his own account of it:

"And thus have I finished what my own experience or relations from my friends have furnished me with on this useful subject of Winds, Tides, Currents,

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&c., which I humbly offer, not as a complete and perfect account but as a rude and imperfect beginning or specimen of what may be better done by other hands hereafter and I hope this may be useful so far as to give a few hints to direct the more accurate observations of others."

The facts about the winds of the oceans must have been largely a matter of common knowledge in those days because our next meteorologist, **Edmund Halley**, the father of dynamical meteorology, published his account of the trade winds and monsoons, with an excellent map, in the year before Dampier's book was published. Halley was indeed a pioneer in meteorology in that he first endeavoured to connect the general circulation of the atmosphere with the distribution of the sun's heat over the earth's surface. Born at Haggerston in **1656**, died at Greenwich in 1742, he was educated at St. Paul's School, and Queen's College, Oxford; he was a great natural philosopher, a great traveller in search of the facts of terrestrial magnetism, a great secretary of the Royal Society, for he it was who persuaded Newton to publish the *Principia*, and a great Astronomer-Royal.

The next of our benefactors who shall be mentioned is **George Hadley**, a younger brother of the John Hadley whose name is associated with the invention of the sextant. He was by profession a lawyer. Born in London in **1685**, he entered Pembroke College, Oxford, in 1700, joined Lincoln's Inn in 1701, and was "called" in 1709. He was one of the coterie of philosophers that gathered at the Royal Society. His benefaction to our science is that he first showed how to make allowance for the rotation of the earth in the explanation of the trade winds in papers before the Royal Society in 1735. His theory ultimately found its way into every text-book of physical geography, perhaps because it occurred to other people independently. Sixty years after it was published John Dalton, referring to one of his own essays, says, "the theory of the Trade Winds was as I conceived when it was printed off original: but I find since that they are explained in the very same principles and in the same manner by George Hadley." I have also seen the same theory claimed in certain quarters as originating with Immanuel Kant, and in the claim it was urged that Kant was hardly likely to have seen the *Philosophical Transactions* which had only been published thirty years before.

Besides his papers on theory Hadley contributed also abstracts of meteorological diaries for the years 1729 and 1730, and subsequently a paper on the meteorology of 1731–35.

I have said elsewhere and still hold the opinion that the theory of the trade winds which Halley started and Hadley improved belong to the fairy tales of science because they explain the complexity of nature by a simplicity which is suggestive of a fairy's wand. They are none the less attractive on that account. Every theory of the course of events in nature is necessarily based on some process of simplification of the phenomena and is to some extent therefore a fairy tale.

After Hadley there is rather a long gap in my history till we come to **James Hutton**, "the first great British geologist," who was born in Edinburgh in **1726**, was educated at Edinburgh, Paris, and Leyden as a physician, but who devoted his life to natural philosophy and natural history; he died in his native city in 1797. He gave us the wet-and-dry-bulb thermometer. To him we owe an attempt to explain

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the physics of the formation of rain. It is contained in a work published in 1784 on the Theory of Rain and its applications, according to which rain is produced by the mixing of masses of air with different temperatures and different amounts of water vapour. The precipitation of water by mixing different specimens of air is dependent upon the fact that the capacity for a mass of air to contain moisture in the gaseous form increases more rapidly than in direct proportion with its temperature; so that when two masses, both saturated, are mixed the mixture is too cold for it to hold all the moisture in the gaseous form, consequently some of it must be deposited as cloud or rain. It is a great step towards comprehending the physical processes of the atmosphere. Since Hutton's time we have come to regard the dynamical cooling of air, which seems to have originated with Dalton, as having more significance than mixing for the formation of a shower of rainfall which may represent something like 1000 million horse-power, as described by Professor Bjerknes in his recent lecture before the Society; but the insight into the effects of mixture is true, and is the more remarkable because the laws of saturation of air as subsequently expounded by Dalton were not then understood.

My next example is of what I suppose may be called a "practical" meteorologist, in the popular acceptation of that term, **Richard Kirwan**, born in 1733, son of Martin Kirwan, Esq., of Cregg, County Galway. He entered the Jesuit novitiate of St. Omer in 1754, but quitted it in 1755 and married, to find himself arrested on his wedding-day for his wife's debts He got over that, however, and lived in London from 1777 to 1787, chiefly interesting himself in the Royal Society, of which he was made a fellow in 1780 and Copley medallist in 1782. His work is remarkable for an estimate of the temperatures of different latitudes (London, 1787) designed to pave the way for a theory of the winds. We thus get a glimpse of another true pioneer of the meteorology of the globe based upon ascertained facts of weather and climate. He left London in 1787, and spent the rest of his life in Dublin, where he died in 1812. "He was consulted as a weather prophet by half the farmers of Ireland." That is perhaps more than can be said of the Daily Weather Service of the present day.

From the meteorology of the globe we turn next to the theory of dew as set out with much detail by **Charles Wells**, Physician to St. Thomas's Hospital. He was born at Charleston, South Carolina, in 1757. His father was the printer of a local newspaper. He was sent to school at Dumfries before he was eleven years old, then to Edinburgh University when he was thirteen, and was back in Carolina apprenticed to a doctor in 1771. He left the revolted colony in 1784 and settled in London. He died in 1817. His work on Dew introduces to us the study of radiation as a meteorological agency. By numerous and careful experiments described in the essay which was published in 1814 he made it clear that the deposition of dew was to be accounted for by the cooling of the objects exposed to the sky on a clear night. His theory of dew has been critically examined by the perspicacious John Aitken, whose loss we have now to deplore, and who raised the question whether the dewdrops were derived from the air, as Wells would have allowed, or from the earth. We may, in consequence, have to picture to ourselves

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dewdrops as exuded by plants when evaporation is inhibited instead of being condensed from the passing air, and the deposited moisture as coming from the local earth; but the process of cooling by which these operations are brought about is correctly ascribed to radiation, and we are introduced to the operation of one of the real causes of the meteorological phenomena of the land as distinguished from those of the sea.

The next on my list is the distinguished chemist and physicist **John Dalton**, the true founder of the physics of a mixture of air and water-vapour and a very enthusiastic meteorologist. Dalton was all his life a student and a natural philosopher, dependent upon teaching for his maintenance. He was born at Eaglesfield, near Cockermouth, in 1766, the son of "a poor weaver undistinguished either for parts or energy who married in 1755 Deborah Greenup, a woman of strong character and, like himself, a member of the Society of Friends." He set up school at Eaglesfield in 1778 at the age of twelve, and, after two years, at Kendal in 1781. He began a meteorological journal with the observation of a remarkable aurora on 24th March 1787, and maintained it for the rest of his life. In 1793 he became professor of mathematics in New College, Manchester, and in Manchester he continued his researches until his death in 1844. For his atomic theory his name is known wherever science is pursued, and his investigations of the laws of pressure of aqueous vapour in air are the foundation of one of the most difficult conceptions which every student of meteorology must make his own. But he was also interested particularly in the study of the aurora. He estimated the height of one of these remarkable appearances in 1793 at 150 miles, and gave the height later on in 1826 from further investigations at 100 miles, which agrees fairly well with the results of the most recent measurements of the present day. His contributions to the physics of the atmosphere include a paper read on 27th June 1800 "on experiments and observations on the Heat and Cold produced by the mechanical condensation and rarefaction of air," and in that he crossed the threshold of the physical explanation of countless phenomena of the atmosphere.

In his report on Meteorology to the British Association of 1832, J. D. Forbes, subsequently Principal of the University of Edinburgh, though at the time a young man of twenty-three, to become in the next year a professor of natural philosophy, in commenting upon the fragmentary treatment of meteorology, remarks, "We find strewed over its irregular and far-spread surface patches of cultivation upon spots chosen without discrimination and treated on no common principle which defy the improver to enclose and the surveyor to estimate and connect them"; and later on, "Mr. Dalton descends for a moment from his chemistry in the abstract to illustrate the constitution of the atmosphere and the theory of vapour." I cannot find that the attitude of the "improver" or the "surveyor," which is perhaps natural to a youth of 23, adequately represents Dalton's appreciation of the study of weather. His devotion to the keeping of his register was in its way as remarkable as his excursions into physical or chemical theory, and his study of the phenomena of the atmosphere was an essential part of his life.

In the last eleven years of his life Dalton received a pension from the Civil List, and the mention of the fact raises the question whether a philosopher of his eminence ought not to be adequately provided for by

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some form of state-endowment and not left to the precarious emoluments of a teacher of mathematics. However that may be, it is rather difficult to imagine how any scheme could have made a life more productive in natural philosophy than Dalton's. He never had time to marry, but he got through an astonishing amount of scientific work.

Luke Howard comes next on the list; he was also a member of the Society of Friends and at the same time a successful man of business. He was born in London in 1772. His father, Robert Howard, was a manufacturer of iron and tin goods, the chief introducer of the argand burner. Luke Howard was educated at a private school in Burford, Oxon, and subsequently apprenticed to a chemist at Stockport. In 1793 he took up the business of a chemist in London, near Temple Bar, with chemical works in Essex. In 1812 he removed to Tottenham, at which or on his estate at Ackworth in Yorkshire he spent the remainder of his life. He died in 1864. He became a fellow of the Royal Society in 1821. His scientific interests were much developed by the Askesian Society (from ἄσκησις, exercise), which was instituted in March 1796 to hold meetings every fortnight at the house of William Allen, F.R.S., Plough Court, Lombard Street, and subsequently at the other members' houses, the last being Dr. Babington's in Aldermanbury. It lasted about ten years. Howard became sufficiently famous, principally on account of clouds, to correspond with Goethe and receive a short poem of acknowledgment entitled "Howards Ehrengedächtniss." His best known works are on the forms of clouds and on the climate of London. He was as assiduous as Dalton in keeping a meteorological register which is continued till 1830.

I need not refer here to his contribution on the classification of clouds, but I should like to mention his *Barometrographia*, a book of some magnificence, which gives a series of curves of the variation of the barometer during a number of years obtained from the "Barometer Clock," a self-recording barograph. In the book are large diagrams in circular form representing the barometer's changes with other particulars of weather. It is to be feared that Luke Howard, in spite of his judicious upbringing and careful scientific nurture, was not quite of the orthodox school of meteorologists as we understand them, for he devoted a good deal of attention to the study of the relation of the weather to the phases and the apsides of the moon. Moreover he actually wrote about a *cycle* of 18 years in the seasons of Britain. Still the question of the moon had presumably to be settled by trial, and now that Professor S. Chapman has pointed out the exact degree of relation we may permit it to be mentioned. Howard lived to the great age of 92.

Next follows **Sir Francis Beaufort**, Rear-Admiral and Hydrographer of the Navy, known to all meteorologists for the Beaufort Scale of Wind Force as indicated by the behaviour of a ship at sea, and the Beaufort notation for weather, whereby its different phases are indicated by letters of the alphabet. He was born in 1774, son of the Reverend Daniel Augustus Beaufort, Rector of Navan, County Meath. His sister Frances married Maria Edgeworth's father. He entered the Navy in 1787. In an interval of unemployment at sea in 1803–4 he assisted his brother-in-law in establishing a line of telegraphs from Dublin to Galway. In June 1805 he was in command of the *Woolwich* and surveyed

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Rio de la Plata, and from that year his scale of wind force is dated. He surveyed the Greek Archipelago and combined the duty with suppressing the pirates of the Levant. He was Hydrographer from 1829 for 26 years, and died in 1857. He was a fellow of the Royal Society. He made no contribution to its publications, but his contributions to the organisation of meteorological observations at sea have been of the greatest value to meteorologists for more than a hundred years. If now there is a tendency towards miles per hour, or metres per second, or kilometres per hour as the only satisfactory representation of the wind, and towards regarding the phases of weather for the purposes of aerial navigation as being too numerous for a notation that is limited to the letters of one alphabet, there will still be a place for the recognition of a meteorologist who saw the practical advantages of definition and of brevity in meteorological records.

Sir Edward Sabine was in his ninety-fifth year when he died. His long life was largely devoted to the meteorology and magnetism of the globe as dependent upon co-ordinated observations in all countries organised by Government in association with recognised scientific institutions. One can hardly over-estimate what the *Réseau Mondial* of magnetism and meteorology of to-day owes to Sabine. He was born in Dublin in **1788**, educated at the Royal Military Academy, Woolwich, became a fellow of the Royal Society in 1818, joined in arctic explorations in the same year with [Sir] J. Ross and in the next year with [Sir] Edward Parry, and was engaged upon pendulum observations in 1821–29; was Secretary of the Royal Society in 1828–29; undertook a magnetic survey of the British Isles in 1834; General Secretary of the British Association for the Advancement of Science from 1839 for 20 years, with the exception of 1852, when he was President. In 1840, with the aid of these scientific bodies, he obtained the establishment of magnetic observatories at Toronto (Canada), St. Helena, Cape of Good Hope, Hobart (Tasmania), and stations in India determined by the East India Company, many of which are still in operation; and meteorological observations were initiated there also. A naval expedition to the Antarctic was also arranged for the purpose of a magnetic survey. The Kew Observatory, Richmond, was obtained from the Crown by the British Association for use as a physical observatory in 1842, and maintained by that body until 1871, when it was provided for partly by the Meteorological Office, which was then maintained by Government by aid of a grant administered by a Committee of the Royal Society of which Sabine was Chairman, and partly by a private benefaction entrusted to the Royal Society by John Peter Gassiot, the Chairman of the Kew Committee of the British Association. This is perhaps the only substantial private benefaction in money which we can commemorate to-day, unless I may add, as in public duty bound, the endowment by Sir Arthur Schuster for six years of a Readership in Meteorology of £350 a year upon most generous terms for the Reader, which has brought into connection with meteorology Lieut.-Col. Ernest Gold and Major G. I. Taylor, with results for the science with which we are all conversant. To the movement of which at least Sabine was the most prominent figure we owe the observatories of Mauritius and Hongkong and the beginnings of the meteorological services of Canada and India. But Sabine's influence

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went much further. In 1852 he secured the establishment of meteorological observations at all the foreign and colonial stations of the Royal Engineers, which were under the general superintendence of Sir Henry James, Director of the Ordnance Survey at Southampton, where a base station was maintained. Under Sir Henry's direction the book of *Instructions* for Meteorological Observations was drawn up which appears in modern form as the *Observer's Handbook* of the Meteorological Office. The foreign and colonial stations of the Army Medical Department were brought to take part in the meteorological work, and in 1862 the whole of that work was taken over by the Army Medical Department. The results of this great meteorological enterprise for the British Empire appear in two publications by Sir Henry James and in the notable volume of *Meteorological Observations at the Foreign and Colonial Stations of the Royal Engineers and the Army Medical Department*, 1852–1886, which was published by the Meteorological Council in 1890, mainly, it must be confessed, in response to an appeal in the *Meteorologische Zeitschrift* by Hann in 1886. The compilation was entrusted, let me remark in passing, to Mr. J. A. Curtis, who is still with us.

Sabine undertook the reduction and publication of the magnetic observations himself with a small clerical staff at Woolwich and continued it for about twenty years, and indeed after the provision for the clerical staff was withdrawn. He had also in hand the repetition of the magnetic survey of the British Isles, 1858–61. He was President of the Royal Society from 1861 until 1871, and within that time pendulum observations were initiated in connection with the Trigonometrical Survey of India, an enterprise started in 1864, which has given most valuable scientific results.

It must be remembered that these great contributions to the meteorological and magnetic survey of the globe were initiated by Sabine long before those surveys were taken up on an international basis. The earliest effort at international meteorology began with the meteorology of the sea after the Conference at Brussels in 1853 initiated by Lieutenant Maury of the U.S. Navy; as a result of that Conference the Meteorological Office of the Board of Trade was established in 1854.

After FitzRoy's death in 1865 the Office was detached from the Board of Trade, and the grant was entrusted to a Committee of the Royal Society, of which Sabine was Chairman. R. H. Scott was appointed Director of the Office, and Balfour Stewart, the Superintendent of Kew Observatory, the Secretary of the Committee. Mr. Richard Strachan and Mr. Charles Harding remain, I think, the only survivors of FitzRoy's establishment under the Board of Trade.

Sabine died at Richmond on 26th June 1883. His capacity for securing the co-operation of scientific institutions with official establishments entrusted with duties which have a scientific outlook we do well to commemorate to-day. It is not given to every one even to keep the peace between the two sides of activity, yet not only peace but active sympathy is a necessity alike of official as well as scientific progress.

John Frederic Daniell, professor of chemistry in King's College, London, from the foundation of that Institution in 1831 until his sudden death in 1845, was born in Essex Street, Strand, in 1790. His father was a bencher of the Inner Temple. He went into business as a sugar

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refiner, but left it to become a fellow of the Royal Society at the age of 23. He began his meteorological contributions in the same year. He is perhaps best known as the inventor of the Daniell cell, but at least almost equally well for the invention of the Daniell hygrometer for the determination of the dew-point. It is an elaborate apparatus in which the cold produced by the evaporation of ether plays a double part. The most interesting fact about the instrument is that it was used by James Glaisher for many thousands of observations of dew-point in comparison with the dry and wet bulbs, and it is on these observations that Glaisher's table of factors for obtaining the dew-point from the readings of the dry and wet bulbs is based and thence the tables for the vapour pressure and relative humidity which are still used in this country, though elsewhere they are replaced by tables based upon Auguste's formula or Regnault's generalised expression of it.

Daniell also interested himself in particulars of the climate of London, of which Howard had made a special study. He was awarded the Silver Medal of the Horticultural Society for an essay on artificial climate in which stress was laid upon the appropriate degree of humidity for greenhouses. His *Meteorological Essays*, which first appeared in 1823, and of which a second edition was published in 1827, contain contributions on the subject of radiation which still invite diligent inquiry. Among other meteorological experiments he set up in 1832 a water barometer in the rooms of the Royal Society, at that time at Somerset House.

The course of history brings us next to the development of our knowledge of revolving storms to which the depressions of our latitudes were shown to be closely analogous by the pioneer work of Buchan and the prolonged investigation of the Meteorological Office under Sabine and Scott.

William Reid, Major-General R.E. and Colonial Governor, was the eldest son of the minister of Kinglassie, born at Kinglassie in 1791. Educated at Musselburgh and the Edinburgh Academy, he entered the Royal Military Academy, Woolwich, in 1806. He was responsible for the construction of the defensive lines of Torres Vedras and other military operations until 1815. From 1824 to 1827 he was in charge of the ordnance survey of Ireland, and in 1831 he was sent to Barbados to rebuild the Government buildings which were blown down by the hurricane of 10th August 1831. He conducted a voluminous correspondence with Wm. C. Redfield of New York upon the subject of West Indian hurricanes, which is preserved in the library of Yale University. He collected data of tropical revolving storms in both hemispheres, and in 1838 he published an attempt to develop the *Law of Storms* by means of facts arranged according to place and time, and hence to point out a cause for the variable winds. A second edition was published in 1841, and a third in 1850. He was elected fellow of the Royal Society in 1839; Governor of Bermuda, and then Governor in chief of the Windward Islands in 1846; Chairman of the Executive Committee of the Great Exhibition of 1851, and in that year Governor of Malta. "He established barometers in public places to warn the shipping and fishermen of impending gales." He died at 93 Gloucester Terrace, Hyde Park, in 1858.

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It is remarkable how these and other contributions to the analysis of the phenomena of revolving storms have been dispossessed of their interest for modern students by the introduction of weather maps based upon isobars, which were unknown in Reid's time. The absence of any reduction of the barometer to sea-level must have made a collection of barometric observations as chaotic as a collection of temperature observations is still. I have no note of when the practice came into general vogue. The formula for it is due to Laplace, but when it began to be general belongs to another part of our subject.

Henry Piddington, author of the *Sailor's Horn Book* for the law of storms for the Indian and China seas (1844), was the second son of James Piddington of Uckfield. He was born in **1797**, bred in the Mercantile Marine, apparently in the East India and China trade, and was for some time commander of a ship. In 1830 he was curator of the Museum of Economic Geology in Calcutta and Secretary of the Asiatic Society of Bengal. In 1839 he began a series of memoirs on the storms of Indian seas based upon information collected from ships. The results are collected in the *Horn Book*. He died in 1858. Piddington is responsible for enriching the language of meteorology with the word "cyclone" to denote a revolving or circular storm. It seems so appropriate that one might suppose it was a Spanish or Portuguese name for a tropical hurricane, but Piddington explains in the *Horn Book* that he coined it from the Greek κύκλος, the coil of a snake, to indicate the curving form of the flow of air.

Perhaps I ought to include the Reverend **William Whewell**, the nearly omniscient Master of Trinity, whose name appears as associated with Sabine and others on many of the Committees of the British Association which did so much for co-operative meteorology. He invented an anemometer during that time of activity, but in writing his history of the inductive sciences he found no place for the history of meteorology because in the end it was only the application of the laws of physics to the special case of the atmosphere. Yet he was professor of mineralogy and had no difficulty in regarding it as an inductive science; and to be quite frank, unless the facts of meteorology are assembled and co-ordinated according to inductive laws after the manner so assiduously followed by our new Symons Medallist,[1] the laws of physics can get no foothold. However, let me add that Whewell was born at Lancaster in **1795**, and, the son of a carpenter, intended for that trade; he died at Cambridge in 1866. Displaying unusual capacity for learning at the Grammar School of Lancaster, he was provided with means to join Trinity College, and died there after a triumphant career as the redoubtable Master of that College.

This brings us to the end of the pioneers of meteorological work who began life before the end of the eighteenth century. They include, as will be seen, men of very various gifts and capacities—sailors, soldiers, gentlemen of quality, professional men of science, and men of business. Between them they managed to show glimpses of initiative in all the various departments of meteorological investigation, the design of instruments, the arts of observing, the compilation of observations, the

[1] H. H. Hildebrandsson (see p. 197).

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organisation of co-operation over wide areas, the study of the physical processes by which the sequence of weather is carried on.

It is curious to note on reading through J. D. Forbes's report on Meteorology in 1832 that the most modern aspects of the science were not disregarded. "A few observations with balloons have been published by Lord Minto in the Edinburgh *Journal of Science*," and further on, "Captain Parry found by means of a kite that the thermometer indicated no diminution of temperature at a height of 400 feet. It stood at $-24°$." As in many other British contributions to the subject the optical phenomena of the atmosphere have not received the attention they deserve. Perhaps we owe some of our backwardness in that subject to the savage treatment which was meted out to Thomas Young to whom now we turn for the fundamental principles of atmospheric optics. Forbes's second report of 1840 is, however, a mine of information on that subject for the curious inquirer.

If my sketch were complete it would bring the subject down to about the middle of the nineteenth century, and from then onward the era of the weather map and of organised co-operation begins. If time permitted an interesting addition might be made by sketching, in like manner, the contributions of those who followed immediately after those whose names I have recited and who carried the matter forward to the full development of the weather map and the monthly chart—George Biddle Airy, Robert FitzRoy, James Glaisher, Richard Strachey, Francis Galton, Alexander Buchan, George James Symons, Thomas Stevenson, Arthur Mitchell, Henry Blanford, John Eliot, Charles Meldrum, William Clement Ley, Ralph Abercromby, Henry Toynbee, Robert Henry Scott.

My lists are, I know, incomplete. If the year 1919 has been a great year for meteorology it has been a very exacting one for those who, like myself, have been closely concerned in its doings. I shall leave you to add the names of those to whom your personal obligations are due.

Remarkable Snowstorm at Jerusalem.

According to information in the Press, snow commenced to fall at Jerusalem on the evening of February 9th, 1920, and continued without cessation for three days and nights until the ground was covered to a depth of between 30 and 40 inches. In drifts it reached very great depths, and it is estimated that the resultant damage amounts to about a quarter of a million sterling. It is stated that not since the year 1860 has so heavy a fall been experienced in the Holy City. Roofs of scores of buildings are said to have collapsed and huts and tents were destroyed. Thousands of sheep and goats perished in the neighbouring country and much distress was caused to the population. Illustrated newspapers in this country reproduced a few weeks later photographs of the unusual scenes which occurred, and British soldiers are seen in the Via Dolorosa standing knee-deep in snow.

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Royal Observatory, Greenwich. Report to the Council of the Royal Meteorological Society for the year 1919. (Communicated by the Astronomer Royal.)

Meteorological observations have been continued as in previous years, with slight modifications. The radium collector for the determination of the Atmospheric Potential Gradient has been brought into regular use. The new earth thermometers mentioned in last year's report were both broken early in the year. New ones were placed in the ground in a vertical position, the holes being filled with sand, and the parts above the ground protected by a small wooden ventilated screen. Since June 1 the readings have been used in the *Monthly Weather Report* of the Meteorological Office.

The temperature of the air varied between 87°·5 F. on August 12 and 15°·5 F. on February 9. 80° was reached or exceeded on 20 days, including 11 in August but none in July. 32° or less was recorded on 64 days, including one in September.

The mean temperature for the year was 48°·4, rather more than a degree lower than the 75 years' average. May was 3°·3 above average, and December 3°·1 above, but February, July, October and November were respectively 3°·9, 5°·2, 4°·7 and 4°·5 below average, July being the coldest July in the whole period of 79 years, the coldest previous July having been the first of the series, in 1841. October and November taken together were also the coldest in the whole series.

1490 hours of bright sunshine were registered, eleven hours less than the 20-years average. May was the sunniest month, with 34 per cent above average; but July had 43 per cent below average. Each of the last three years has had sunshine within 1 per cent of the average. There were 80 sunless days, and 8 days with at least 90 per cent of possible sunshine, the sunniest being May 19, with 94 per cent.

The highest reading of the solar radiation thermometer with black bulb *in vacuo* was 163°·6 F. on August 17, and the lowest reading on the grass was 11°·5 F. on February 10 and 12. The difference between the highest and lowest radiation readings exceeded 100° on 28 days, the greatest difference being 118°·8 on August 17.

The total rainfall was 23·04 inches or 1·19 inches below the 75 years' average 1841–1915. The greatest monthly total was 3·24 inches in December, but March with 2·97 inches was relatively the wettest month, 88 per cent above normal. The driest months were May with 0·57 inch, 70 per cent below normal, and October with 0·85 inch, 69 per cent below normal. There were 166 rainy days (midnight to midnight), ranging from 5 in May and 6 in June to 21 in March, 23 in January, and 25 in December. There were no rain spells, and the only absolute drought was from May 10 to 24 inclusive. The wettest days were June 20 with 1·14 inches, and April 27 with 1·08 inches; six other days had falls of half an inch and upwards, including August 28 with 0·85 inch.

The total movement of the air recorded by Robinson's anemometer was 101,022 miles, about 3 per cent below the average for fifty years. The greatest pressure recorded was 19·5 lbs. to the square foot on December 2. The greatest daily movement was 670 miles on March 27, and the greatest hourly velocity 48 miles for the hour ending 3 a.m. on November 24. The least daily movement was 81 miles on January 24.

F. W. Dyson,
Astronomer Royal.

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THE STATUS OF A METEOROLOGICAL OFFICE AND ITS RELATION TO THE STATE AND THE PUBLIC.

By Captain C. J. P. CAVE, M.A., F.R.Met.Soc.

A METEOROLOGICAL service is a practical necessity in a modern civilised state, and though all large states have such a service, there is probably not one which is as good as modern science and enterprise might make it. In the following notes I have attempted to put down what to my mind should be the status of a meteorological department, and what should be some of its activities. As I have no official connection with the Meteorological Office, beyond having helped it during a part of the war, my views may possibly not meet those of official meteorologists. Nevertheless there are several broad principles which may meet with general agreement.

The Meteorological Office must be a Government Department subsidised from the public funds. This has not been the case in the past with our own Office, which was under the Meteorological Committee, a body on which several Government Departments were represented. The Office received a grant in aid, and if this were not exceeded the money could, I believe, be spent in any way the committee considered proper. This arrangement was probably an excellent one in former times, as it left the Office free to develop on its own lines. To-day, however, Meteorology is becoming so important to many departments of the State that it is rather anomalous for these to have to apply to a semi-private institution in matters of such importance. Moreover the question of money is practically a deciding factor; with many new developments it is hardly possible to continue the Meteorological Office on a grant in aid.

If then it is to be a Government Department spending public funds it is a *sine quâ non* that it must come under some existing Ministry, for we can scarcely expect Parliament to create a Minister of the Weather. There is however an ideal arrangement, which is purely Utopian, and which I only mention as such, by which such bodies as the National Physical Laboratory, the Royal Observatory, the Hydrographic Department, the Department of Scientific and Industrial Research, and many others, as well as the Meteorological Office, should be under a Minister of Scientific Departments. Such an ideal however is one for which I fear we are not ready, and therefore the Office must come under some already existing Ministry.

In practice it would not much matter what this Ministry was, if the Meteorological Committee were allowed a free hand. The Director ought to be one of the permanent officials of the Ministry, and not under other permanent officials who would not have the requisite knowledge of the details of the work; that is to say he must be directly responsible to the Minister for the general work of the office. The office should have its own vote and account, and the Meteorological Committee might well be directly responsible to the Minister for the expenditure of the funds. The question of funds is most important; if the funds of the office were merged in the general account of the Ministry there would be no guarantee that the office would receive its due. In such a case the officials in

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charge of the funds of the Ministry would be more than likely to economise by cutting down the expenses of a department whose scope they would not be in a position to understand, and many of whose activities would have no bearing on the needs of that particular Ministry.

To take a hypothetical case: suppose the Office had been under the Board of Trade; the latter looking at the case from its own point of view might very legitimately say that the functions of the Office were to supply weather forecasts in connection with shipping; in the days before aeroplanes, when the Office was already beginning to organise the study of the upper air, the Board of Trade might have said, reasonably from their own point of view, that the subject of the upper air was of purely academic interest, and was unconnected with the practical objects for which the Office existed; that if scientific men felt an interest in the upper air, it was for unofficial bodies or private persons to investigate it; that it was not for a Government Department to take up a research of which the practical utility was not apparent. Such an attitude would be extremely unscientific, but permanent officials of Government Departments have not always had the training requisite for forming a judgement on scientific requirements. Moreover the officials of one department can hardly be expected to appreciate the bearings of research that does not touch their own department. An official of the Air Ministry can scarcely be expected to see the importance of temperature and rainfall which would be of immense importance to the Board of Agriculture; the Board of Agriculture could hardly be expected to become enthusiastic about the wind in the stratosphere; the variation of the wind at St. Helena, or barometric fluctuations in the Southern Hemisphere, might not appeal to the Ministry of Health. It is only the Meteorologist who can look on all the various sides of the science and see each in its proper proportions, and in their relations to each other. If the Office were at the beck and call of one Ministry, which in practice directed its activities, as would happen if payments on account of the Office were to become merely part of the general account of the Ministry, it is more than probable that many branches of meteorology would be neglected. The Office must therefore have its separate vote and account.

A scientific body must not be hampered in its work by unscientific control. The grant of money must of course be controlled, as any grant from public funds, but it does not add to efficiency when those who have not had the education or experience to enable them to appreciate scientific matters, attempt to judge work of a scientific nature. If one were going to construct a large waterworks scheme one would consult a rainfall expert, but one would not give him control of the engineering operations.

And here I should perhaps say a word as to the appointment of a director, not only of the Meteorological Office, but of other scientific bodies under Government control. In spite of all that has been said, and in spite of all that the war has taught us, we have not yet learnt the lesson that it requires a man of the best training, and of the highest capability in his own branch of science, to preside over a scientific institution. Only in this way can the institution keep the position that it should keep; only in this way can real efficiency be maintained.

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Having discussed very shortly what should, to my mind, be the status of a Meteorological Office, I may perhaps be allowed to indicate very briefly the importance of such an Office to the Government, to the public, and to the science of meteorology. One need hardly mention the various points in which the Office serves the country and the public. The Board of Trade are interested in forecasts, as are also the Admiralty, the Air Ministry, and the Board of Agriculture; moreover the population in general, and especially agriculturists, are intimately concerned in forecasting, or should be. Statistics of wind and weather at sea concern the Admiralty and the Board of Trade; statistical information from other parts of the globe concerns the Colonial and India Offices and the Ministry of Health; statistics referring to the British Islands concern the Board of Agriculture, the Ministry of Health, and the Board of Education. Rainfall concerns not only various Government departments, but such bodies as County Councils, Municipal bodies, and organisers of engineering undertakings.

There is no department, probably, which knows as yet how great a use it may make of meteorology, and for this reason the Office is in a peculiar position, since it must be in touch with many departments, and should therefore not be under the complete control of one.

With regard to the public in general it has always seemed to me that full use is not yet made of the information that is to be had from the Office. The public do not realise what forecasting can do, and this seems to me to be due to the delay there is between the time the forecast is made and the time the public gets it. It is true that special arrangements can be made by which farmers can get forecasts at the times of haymaking and harvest, but comparatively few, I believe, make use of these facilities, partly because they are not widely known, and partly because forecasts are not looked on seriously by the general public. It has always seemed to me that the Government should arrange for the sending out of forecasts. Why should not every postal telegraph office in the country receive a forecast every morning, based on the 1 a.m. or the 7 a.m. observations? Such a forecast could be telegraphed at the same hour as the time message, and telephone subscribers could ring up and get it repeated at a small charge; while a copy of the forecast could be posted up in the window of every telegraph office. There would be no need to telegraph a long message; the report would be in general terms, and a five-figure code could be made to cover practically every variety of forecast. I feel sure that if such an arrangement were adopted it would soon be widely appreciated and would, at any rate to agriculturists, prove a very real boon. Possibly the money saved to the nation through a timely gathering in of crops would far more than balance the cost to the Post Office. At the present time we have to rely on the daily papers which give the forecast based on the 6 p.m. report of the previous day, and a good deal of the distrust of forecasts, which undoubtedly exists in the mind of the public, is due to this cause.

The science of Meteorology is in a curious position compared with other sciences. All science is co-operative, but none to such an extent as meteorology. It is for this reason that the Meteorological Office must be the centre and guiding body in meteorological research. Certainly in the past it has always been ready to help investigators:

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would it have been so available if it had been a dependant of some one Government department?

There has always been the heartiest co-operation between the Office and this Society, and I feel sure that all members will agree with me that if the Meteorological Office had been hampered in its activities by unsympathetic control, the science, which it is the object of this Society to advance, would not have been in the position it holds to-day.

As members of this Society know, the Meteorological Office has during the last year become attached to the Air Ministry, though its exact status is not quite clear, at any rate to those outside official circles. From what I have said it would seem that if the Office becomes a department of the Air Ministry, without a separate vote and account, there is a danger that it will become a mere forecasting branch of the Ministry. It seems to me that before such an important step is taken as that involved in handing the Office over to a Government Department, an official inquiry should be held to consider the whole question of the functions of the Meteorological Committee and the status of the Meteorological Office. In former times this has been the practice whenever any change was made, and three inquiries have been held, the last one in 1904, when the recommendations of the committee of inquiry resulted in the establishment of the Meteorological Committee as it has since existed. Apparently most important changes have recently taken place in the status of the Office, without, as far as I am aware, any adequate inquiry or consultation with any scientific authority, and without any public pronouncement.

I hope the work done before and during the war by the Meteorological Office will not be forgotten. In spite of statements that have been made, upper air research had not been neglected; this Society does not need to be reminded that the Meteorological Office was concerned with matters appertaining to the upper air before the Wright brothers had made their first flight, and when the war came it was the Office that started the work in France, work which soon proved that meteorological information was a necessity at the front.

The Meteorological Department of the Royal Naval Air Service, afterwards taken over by the Royal Air Force, which worked at airship stations in this country, and I believe for a time at one or two stations on the north-east coast of France, carried on observations by methods which the Meteorological Office had already made available, but practically all the meteorological work overseas was done by the Meteorological Office and the Meteorological Section of the Royal Engineers, which was commanded and largely officered by members of the staff of the Office. The work of these two bodies made long-distance night flying a practical possibility, and also added most materially to the accuracy of artillery fire. The creeping barrage required extreme accuracy, and the meteorological work of the Office and of the Meteorological Section, by contributing largely to this accuracy, was the means of saving many thousands of British lives.

I hope it may be realised from what I have said that meteorology must be a national service, but the policy of handing it over to one Ministry, without a separate vote and account, would not be of advantage either to meteorology as a science, or to the meteorological service of the State.

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DISCUSSION.

The President (Mr. R. H. HOOKER) said that Captain Cave had brought before the Meeting a paper on a most important subject. There was a resolution to be submitted to the Meeting which he would ask Mr. Mellish to move; and he thought it would be convenient to take the discussion on that and on the paper together.

Mr. H. MELLISH said it was not the Society's usual practice to bring forward a resolution of the kind he was going to move, but the reconstruction of the Meteorological Office now going forward was so important that the Council felt some steps should be taken before the matter went any further. He then moved the following resolution:

"The Royal Meteorological Society observe that in the Air Estimates for 1919–20 published last December there appears a sum of £12,000 as a supplement to the grant in aid of the Meteorological Office. It would appear from this that it is intended that the finances of the Meteorological Office shall pass under the control of the Air Ministry.

"The Meteorological Office deals with a variety of problems of high scientific and practical importance, some of which have no bearing on the work of the Air Ministry, but are closely connected with the work of other Government Departments. While recognising to the full the great benefits to the Meteorology of the upper air likely to accrue from a close association with the service to which a knowledge of the upper air is so essential, and which possesses such facilities for its investigation, this Society cannot but feel misgiving that there may be a tendency for other branches of Meteorology to receive less than their due attention if one Government Department has the sole control of the finances and management. The Society therefore are of opinion that the Meteorological Committee should continue to have full control of the expenditure.

"It has been the practice in the past before any change was made in the body administering the Meteorological Office for an inquiry to be held by a Departmental Committee. Reports of three such inquiries have been published, the last being that issued in 1904 of a Treasury Committee presided over by Sir Herbert E. Maxwell, Bart. The Treasury did not adopt the whole of the recommendations of this Committee, but on May 20, 1905, they issued a Minute constituting the Meteorological Committee as it has since existed. The Society are of opinion that before the future constitution of the Meteorological Committee and the status of the Meteorological Office are finally settled, it is very desirable that an inquiry by a representative Committee should be held."

The Office was now managed by the Meteorological Committee on which the Royal Society and four Government Departments were represented, and it appeared to the Council most desirable that before this Committee was absorbed by any one Department there should be a full inquiry into the whole question. It was suggested that the Fellows should authorise the Council to approach the Treasury, and they would also endeavour to get the support of the Royal Society.

Captain C. J. P. CAVE seconded the resolution.

The President said that as a Civil Servant he proposed to take no part in the discussion on the paper or the resolution. He would only add that it was in recognition of the difficulty in which some Fellows of the Society who were officials might feel themselves placed that the Council had avoided putting any members of the Air Ministry, the Meteorological Office, or any Government Department on the Committee which had considered the whole matter and drafted the resolution now before the Meeting.

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Dr. H. R. MILL said that the paper by Captain Cave was worded in such a cautious and general manner that it was possible to deal with the real essence of the subject without venturing upon any dangerous questions of detail regarding which information was lacking except to members of the official meteorological services. From his own unofficial knowledge of scientific departments attached to different Ministries he thought that Captain Cave was a little too cautious in his suggestions. Instead of saying that it was absolutely necessary that the Meteorological Office should be under some existing Government Department he might have allowed meteorologists to revel a little longer in the hope of that new heaven and new earth of perfect organisation which the Reconstruction Ministry had once led them to hope for. Although that Ministry had come to an end it was allowable for a scientific society to suggest what they thought would be an ideal arrangement, and leave the cramping of the ideal to officials who would be obliged to fit it into existing conditions. He did not think it would do to have the Meteorological Office responsible to several Ministers: to be saved from the lion at the head of one department to be thrown to the wolves of a dozen departments would not help very much. It was a matter of common knowledge that friction could arise between different departments, and to have two or more Ministers responsible for one service would inevitably give rise to difficulties. It seemed to him that the constitution of the Meteorological Office had, as a result of the various inquiries which had been held, gone on improving steadily, and the constitution arrived at in 1905 seemed to him in essentials by far the best that any scientific body working under Government could have. It was, in his opinion, essential that any body dealing with a subject like Meteorology should be free and unfettered. They must not run the risk of being told by a Minister interested in one particular aspect of the atmosphere that they were to deal with that alone and ignore the rest. They should, on the contrary, be the advisers of the Minister. It seemed to him that much could be done by enlarging the Committee responsible for the Meteorological Office by putting on it representatives of the Ministry of Health, of other scientific bodies, and of public professional bodies like the Institution of Civil Engineers, thus widening the representation of Government Departments and of public needs, and by leaving the Director free from all red tape worries which could very well be dealt with by a Secretary who had nothing to do with the scientific working of the institution. An ideal solution might be that all scientific bodies of a similar character supported by Government should be associated together under a Minister who would be responsible to Parliament for them all, but who would not encroach on the rights of individual Directors to manage their own affairs, the department of each science having self-determination. That would be advantageous to the smaller scientific bodies attached to Government Departments. At present soreness was felt in many departments (he did not refer to Meteorology) because of the interference of the administrative side with the scientific side on which also there was little scope for advancement, and the man who has no hope of advancement is bound to be discontented, and his work must deteriorate. If all scientific departments were grouped under one department the members scattered through various Ministries could look forward to getting higher positions in a purely scientific line. Another desirable reform would be to establish individual responsibility. In Government Departments the responsibility was passed upwards, evaporating as it went, until finally it might become impossible to secure redress for, say, an erroneous weather forecast without dismissing a Cabinet Minister. Ministerial responsibility in such cases was a mere figment, but if, say, every weather forecast had the name of the particular Government servant attached to it, people would look at the forecast one day and if it had John Jones's name to it decide that it was likely

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to be good, but if next day it had Tom Smith's name attached they might not have so much faith in it, and if the event justified it the result might be that John Jones would get promotion and Tom Smith would have to go. Another point was that a scientific department must not be put into a cast-iron enclosure. It should have the power and permission to expand according to circumstances, and to develop along the line which was most important at a particular moment. It should, for instance, be possible to spend more in one year than in another, and there should be no risk of losing a portion of the grant for a year in which it was not found necessary to spend the whole sum allowed. He suggested that before the final decision was taken as to the future of the Meteorological Office, if it had not yet been taken, as wide an investigation as possible should be held, and he greatly deprecated the overturning of a satisfactory system of control without a full public inquiry to ensure that the new arrangements were better than the old.

Colonel H. G. Lyons said that while Captain Cave advocated that a State service of meteorology should be attached to a Ministry of State, he seemed to fear the restrictions that might be placed on that service by the Ministry to which it belonged. Colonel Lyons believed that this need not necessarily be the case, but that two safeguards were desirable. The first of these was a strong Advisory Committee which in the case of a scientific technical service would naturally be predominantly scientific, and secondly, the work of that service should appeal to and be required by as wide a circle as possible, both among Government Departments and the public. With a strong Advisory Committee the service would have the backing of independent men of position in their line of investigation, while the Ministry would have a guarantee that no immature scheme would be put forward.

Dr. J. Brownlee said that the Medical Research Committee had been in the same position as the Meteorological Office appeared to be in. The new arrangement was, that they acted under the Privy Council. This was a much more ideal arrangement than being under a Government Department. Scientific research requires complete freedom. Under the Ministry of Health it would be impossible to publish as scientific investigations conclusions which reflected on the administration of the department. It seemed to him that the Meteorological Office should be put in the same position. A committee of eminent scientific men with assessors from all the interested Government Departments should be in charge. The point about money was very essential. What was not spent in one year should be there to spend in another, because a very slight change in knowledge might give rise to new lines of investigation which should be followed up while people were still enthusiastic.

Mr. G. M. B. Dobson said that the real point was that the Meteorological Committee as at present constituted should continue to control the Office. He understood that the Committee was coming to an end, and that the Meteorological Office would be controlled by officials in the Air Ministry who had Civil Service qualifications rather than scientific ones.

Dr. C. Chree said that as a member of the Meteorological Office he had not taken part in the debate, and did not intend to vote, but he thought that it should be made clear that abstention from voting did not mean approval or disapproval.

Mr. J. S. Dines said he wished to associate himself with what Dr. Chree had said. As a member of the Meteorological Office and also a Secretary of the Society, he felt himself on the present occasion to be placed in a somewhat awkward position. He proposed under the circumstances to take no part in the discussion of Captain Cave's paper, or in the voting upon the resolution put forward by Mr. Mellish.

Mr. W. W. Bryant said he was a Civil Servant and a Secretary of the

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Society, and he thought that the point to be emphasised was whether the Meteorological Committee was coming to an end. As long as that did not happen the Air Ministry would be as useful as any other for providing accommodation for the Office.

Captain C. J. P. CAVE said in reply that the gist of the whole thing was that the situation was very obscure at present, and anxiety was felt as to what the future status of the Meteorological Office was going to be. It seemed to him that the Society's request for an inquiry was quite reasonable, and could not be misunderstood anywhere.

The PRESIDENT then put the motion to the Meeting, and it was carried *nem. con.* He expressed the cordial thanks of the Fellows to Captain Cave for his paper.

Publication of Abstracts of Papers.—A proposal has been made that a series of abstracts of meteorological papers which appear in different British and Foreign journals should be added to the Bibliography published regularly in the *Quarterly Journal*. The Council feel that the addition of a brief account of the contents of the more important papers which are included in this list would add considerably to its value. This would especially be the case with those Fellows who live far from access to a meteorological library, and are thus unable without considerable trouble to refer to many papers which from their titles appear likely to be of interest to them.

For the preparation of such abstracts the Council desire to enlist the active co-operation of Fellows, and they therefore appeal to all who can do so to offer assistance in this work and to communicate with the Assistant Secretary, stating with what foreign language they are familiar. The abstracts would be quite short (about 100 words in length).

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ATMOSPHERIC AND TERRESTRIAL RADIATION.

By W. H. DINES, F.R.S., F.R.Met.Soc.

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In a paper read before the Society in February 1917, "The Heat Balance of the Atmosphere," [1] the amounts of the various kinds of radiant energy crossing the upper and lower limits are considered; in the present paper an estimate is made of the atmospheric and terrestrial radiation crossing any level surface in the atmosphere itself, certain assumptions being made and certain conditions assumed.

For the method of calculation I am indebted to Mr. L. F. Richardson; this method is being published, but by his kind permission I am enabled to set it out here.

The atmosphere is divided into layers of equal mass; each layer is giving out radiation on both sides and is at the same time absorbing a certain proportion of the radiation from the earth and from the other layers that is passing through it. It is assumed that the radiation emitted by any layer is proportional to the fourth power of its temperature measured on the absolute scale multiplied by a certain factor, η, called the emissivity; and further that the proportion of the radiation passing through any layer that is absorbed is η, and the proportion transmitted is $1 - \eta$. This appears to be justifiable from the general laws of radiation. For example let us consider the net radiation that is crossing the boundary between the second and third layers from the top. To do this we must treat the downward and upward radiation separately. The downward radiation is the radiation from the second layer, and such part of the radiation from the first layer as has escaped absorption by the second layer. The upward radiation is the radiation from the third layer and such portions of the radiation from the fourth, fifth, etc., layers and from the earth as have escaped absorption on their way up.

As stated above, it is assumed that the radiation emitted on each side of any layer is $\eta\sigma T^4$. Of these quantities η is the most uncertain; it varies of course with the mass of the layer, and it also varies widely with the humidity and the amount of cloud in any particular stratum. In dry air and for a stratum containing one-tenth of the mass of the atmosphere, Mr. Richardson gives the value 0·23. This value is adjusted so that we may approximately ignore the ineffective horizontal component.

Taking the unit of one gramme calorie per square centimetre per day I have taken the value of σ, Stefan's constant,[2] as $1{\cdot}10 \times 10^{-7}$ ($5{\cdot}30 \times 10^{-5}$ ergs cm.$^{-2}$ sec.$^{-1}$).

With regard to T the mean value for England or Europe is known up to a height of about 20 k. The values in the calculation given below are mean values for England and have a probable error of less than 1° C., except for the top layer. For all feasible values of T the value of $T^4 \times 10^{-7}$ lies between 100 and 1000, and since $T^4 = (T^2)^2$ the

[1] *Q. J. R. Meteor. Soc.*, **43**, 1917, p. 151.

[2] The precise value of the constant seems somewhat uncertain. Different authorities give different values.

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value of $T^4 \times 10^{-7}$ to the nearest integer is readily obtained from a slide rule by a single setting. As soon therefore as η and T are settled the value of $\eta\sigma T^4$ is readily calculated.

It would probably suffice to divide the atmosphere into five equal portions but ten have been chosen. It has been found by actual trial that the calculated flux of radiant energy across any plane hardly differs whether the division be into ten or twenty equal parts, but using ten requires only half the arithmetic involved in using twenty, and since ten and twenty give practically the same result it follows that the method of dividing into ten gives a reliable result.[1]

It must be frankly confessed that at the present time we can hardly do more than guess at the value of η. Even supposing we knew precisely the value for ordinary air containing carbonic acid and water vapour we should still be ignorant of the percentage of vapour in the various layers. But fortunately, as the following figures will show, the flux of radiant energy is not very closely dependent on the value of η. Perhaps "fortunately" is the wrong word, for if the radiative conditions do not depend very greatly on η, it follows that η cannot be accurately determined from observed meteorological conditions. This perhaps is partly the cause why Lieut.-Col. Gold could not obtain satisfactory results from the Potsdam observations.[2]

To show the method, the calculation is given for the special case of $\eta = \cdot21$ in the uppermost stratum increasing uniformly to $\eta = \cdot39$ in the bottom stratum. The atmosphere is divided into ten sections each contributing 100 mb. towards the total pressure, and each section is treated separately. Precisely similar conditions would hold if we replaced a stratum of air by a sheet of black but perforated metal at the same temperature with $1 - \eta$ of the sheet cut out by the perforations.

The calculation proceeds thus by the use of a slide rule. The figures in column 5, headed $\eta\sigma T^4$, give the equivalent vertical radiation from each side of the stratum. The next column, F_1, is the downward flux, and is formed thus. Solar radiation is not considered, so that at the outer limit of the atmosphere there is no downward radiation and 0 is entered in the column. At the next boundary, viz. at the surface where the pressure is 100 mb., there is a radiation of 53 from the first layer, so 53 is entered. Of this 53, $1 - \eta$ or ·77 will pass unabsorbed through the second layer and reach the bottom of the second layer. The second layer itself will contribute 58 downward radiation, so that the whole flux will be $58 + \cdot77 \times 53$ or 99. Over the next boundary the flux is $68 + \cdot75 \times 99$ or 142 and so on. The next column is the upward flux; it starts with 705 the radiation of the earth as a black body at 283° a., the mean temperature of the ground in England S.E.

[1] If η be the emissivity for any stratum and we desire the value, η_n, for $1/n$ of that stratum, it is given by the equation $(1 - \eta_n)^n = 1 - \eta$, and neglecting squares of η_n, when $1/n$ is a small fraction,

$$\eta_n = \frac{1}{n} \log_e \frac{1}{1-\eta}$$

or using common logarithms to the base 10,

$$\eta_n = \frac{2{\cdot}302}{n} \log \frac{1}{1-\eta}.$$

[2] *Q. J. R. Meteor. Soc.*, **39**, 1913, p. 253.

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Of this 705 × ·61 is transmitted through the bottom stratum up to the point where the pressure is 900 mb. The stratum itself is giving out 264 from its upper boundary, making a total of 694. Across the next boundary we have 694 × ·63 + 236 or 673 and so on. The next column gives the net upward flux which is simply $F_2 - F_1$.

The last column refers again to the stratum and not to the boundary; it is the net gain or loss to the stratum in gramme calories per sq. cm. per day. It is, of course, the difference in the values of the net radiation entering at the lower and leaving at the upper boundary. It is considered negative where the stratum is losing heat, positive where it is gaining heat. Or put in another way, a negative sign means that a stratum is being warmed by some means other than long wave radiation

TABLE I.—METHOD OF CALCULATION.

Pressure. - mb.	Height. k.	η.	T.	$\eta\sigma T^4$.	F_1.	F_2.	F_3.	
0					0	353	353	
		·21	219	53				− 26
100	16·0				53	380	327	
		·23	219	58				− 7
200	11·7				99	419	320	
		·25	223	68				+ 6
300	9·1				142	468	326	
		·27	233	88				+ 3
400	7·1				192	521	329	
		·29	246	117				− 13
500	5·5				253	569	316	
		·31	256	147				− 27
600	4·2				322	611	289	
		·33	265	179				− 39
700	3·0				395	645	250	
		·35	271	208				− 42
800	1·9				465	673	208	
		·37	276	236				− 43
900	1·0				529	694	165	
		·39	280	264				− 46
1000	0·1				586	705	119	

and a positive sign that it is being cooled. This follows from the fact that no systematic change in its temperature is occurring.

The general result of the calculation is to show that the strata from 1000 to 400 mb. pressure are receiving heat from other sources, which may well be solar radiation and the latent heat of condensation of aqueous vapour. The two top strata are receiving heat which so far as I can see can only be from solar radiation. The two layers between 400 mb. and 200 mb. are being cooled probably by the mixing by wind of the layers of the troposphere. Such mixing tends to cause a flow of heat downwards to form an adiabatic lapse rate and hence to cool the upper and warm the lower parts of the strata that are mixed.

The example given refers to a special distribution of η, but I have worked out some twenty to thirty cases and got in each case the same general result. The upper strata of the atmosphere are free from cloud, and on account of their low temperature hold very little water vapour, hence for them the value of η must be low. For a cloudy stratum η

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can hardly be less than ·40, but I doubt if it can ever reach ·70 or ·80. For it is seldom that a cloud layer is thick enough to cause a serious want of daylight, and from the experience with lighthouses round the coast, one may infer that radiant heat should pass through clouds more easily than light. It was found that the comparatively short wave radiation from the electric arc was less capable of getting through a fog than the longer wave radiation from a gas or oil burner, and for this reason gas or oil was preferred for a light. Hence it may be inferred that the long wave radiation from a body at 300° a. is transmitted through a cloud better than light is, and if so η can never reach a very high value. However this may be, I have taken sundry arbitrary distributions of η and calculated the corresponding flux of radiant energy. The results are given later, but to save space the details of the calculation are omitted. Some values that are of interest are added :

E The lowest value in column F_1, that is, the radiant energy passing from the air to the earth.

F + K The topmost value in columns F_2 and F_3, that is the radiant energy leaving the earth. (The letters are taken from the notation of the previous paper, *loc. cit.*)

K The amount of radiation from the earth that is transmitted.

C + L The algebraical total of the last column with the sign changed.

K + x The bottom value of column F_3.

The K is easily calculated from the 10 values of η since

$$K = \sigma T^4 (1 - \eta_1)(1 - \eta_2) \ . \ . \ . \ (1 - \eta_{10})$$

where T is the temperature of the earth's surface. If we could determine K with certainty we could determine the geometrical mean of $1 - \eta$.

These values are of interest because they have been obtained by other workers and by entirely different means.

In Table II. the results of thirteen different distributions of η are given. The upper line gives the value of η assumed for each layer, and the lower line the loss or gain of heat in each layer due to that particular distribution of η. It may be well to state here that 24 gramme calories supplied to any layer will raise that layer 1° C. in temperature, also roughly on the average a layer with a value of − 20 against it is some 12° to 13° C. above the temperature required for radiative equilibrium. Some of the distributions can hardly be considered possible, the $\eta = ·10$ and the $\eta = ·50$ throughout for example. I think that Nos. 7, 8, and 9 perhaps give best the average conditions for this latitude. No. 12 is meant to represent a clear sky save for a layer of cirrus cloud at 9 k. height and No. 13 a layer of strato cumulus at 5000 ft., a common condition in a winter anticyclone.

But whatever distribution of η be taken the same general loss of heat by radiative processes in the first six layers, 0 − 7 k., is shown. These layers are radiating more than they receive, the net loss running to about 200 g.c. per day. As already stated most of this is probably supplied by the latent heat of condensation of water vapour and by contact with the ground warmed by the sun. In the previous paper this was denoted by L, and 200 g.c. per day as a mean for the earth

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were assigned to these combined sources of heat. There is also the effect of direct solar radiation (c) absorbed by the air, and another source of warming that is best discussed in connection with the next two layers.

The next two layers covering the height of 7·0 to 11·7 k. show on the whole a positive value of about 20 g.c. That is to say, they are together receiving 20 g.c. by long wave radiation per day more than they are losing. They must also be absorbing some solar radiation which we

TABLE II.

Reference Number.	50 mb.	150	250	350	450	550	650	750	850	950	E.	K+σ.	K.	F+K.	C+L.
1	·10	·10	·10	·10	·10	·10	·10	·10	·10	·10	319	380	246	500	111
	3	13	10	5	−8	−11	−24	−29	−37	−33					
2	·20	·20	·20	·20	·20	·20	·20	·20	·20	·20	480	220	76	391	168
	−14	5	11	9	−6	−26	−30	−35	−40	−44					
3	·23	·23	·23	·23	·23	·23	·23	·23	·23	·23	509	194	52	370	176
	−25	0	13	12	−4	−21	−31	−36	−40	−44					
4	·30	·30	·30	·30	·30	·30	·30	·30	·30	·30	560	144	20	326	181
	−42	−5	16	14	−4	−16	−31	−35	−37	−41					
5	·40	·40	·40	·40	·40	·40	·40	·40	·40	·40	604	100	4	290	186
	−70	−11	19	12	−3	−13	−26	−30	−32	−36					
6	·50	·50	·50	·50	·50	·50	·50	·50	·50	·50	630	73	1	273	186
	−92	−22	19	24	1	−10	−23	−25	−26	−31					
7	·23	·24	·25	·26	·27	·28	·29	·30	·31	·32	561	145	29	358	213
	−31	−4	10	5	−9	−21	−31	−37	−49	−44					
8	·21	·23	·25	·27	·29	·31	·33	·35	·37	·39	586	118	20	353	234
	−26	−7	6	3	−13	−27	−39	−42	−43	−46					
9	·20	·20	·25	·30	·35	·40	·50	·60	·60	·40	628	76	4	342	267
	−23	−12	−3	−5	−27	−40	−55	−52	−32	−18					
10	·23	·23	·25	·30	·40	·50	·70	·80	·90	·40	649	55	2	330	273
	−31	−8	6	−4	−44	−59	−73	−39	−9	−8					
11	·11	·13	·15	·17	·19	·21	·23	·25	·27	·29	512	191	74	426	234
	1	1	5	0	−15	−24	−38	−39	−52	−52					
12	·23	·23	·50	·23	·23	·23	·23	·23	·23	·23	516	188	34	333	144
	−35	−14	17	24	8	−12	−22	−32	−36	−42					
13	·23	·23	·23	·23	·23	·23	·23	·23	·50	·23	556	147	34	366	219
	−22	−2	12	10	−7	−20	−33	−40	−86	−30					

may perhaps put at 10 g.c., but they are probably above the level at which any appreciable amount of vapour is condensed. Thus a cooling equivalent to 30 g.c. per day or 0°·6 C. has to be accounted for. This is no doubt due to the forced mixing of the atmosphere by wind which sends heat downwards; such mixing if carried far enough would produce an adiabatic gradient of 10° per kilometre height, whereas the usual gradient is only 6°; it would therefore cool the upper and warm the lower strata.

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The two topmost layers again are on the whole radiating heat like the lowest six layers; but the amount, since the temperature of the top layer is doubtful, is somewhat uncertain.

Of course the whole loss of heat by radiation must be made good by other means since the temperature is not falling. This is the L + C in Table II. In the previous paper reasons were given for putting this value at 260 g.c. If the present calculation is right, the 260 g.c. is too high, but the 260 was taken as a mean for the earth, and the present calculation uses the temperatures found over England.

With regard to the other quantities, a different value of σ is used here giving 705 for the earth's radiation at 283°. In the previous paper it was taken as 500 g.c. at 288°, a value based on Bottomley and King's experiments, but no doubt too low. This makes any comparison difficult. But the value of $K + x$, the net upward radiation at the

TABLE III.

Reference Number.	50 mb.	150	250	350	450	550	650	750	850	950	E.	K+x.	K.	F+K.	C+L.
						CYCLONE.									
14	·20	·20	·25	·30	·35	·40	·50	·60	·60	·40	605	99	4	339	233
	- 40	- 26	- 14	- 4	- 12	- 26	- 36	- 32	- 20	- 26					
						ANTICYCLONE.									
15	·23	·23	·23	·23	·23	·23	·23	·25	·25	·25	531	173	55	374	209
	- 12	9	15	1	- 16	- 32	- 38	- 42	- 42	- 41					
						EQUATORIAL.									
16	·20	·20	·20	·20	·20	·20	·20	·20	·20	·20	588	302	96	433	132
	38	45	24	2	- 10	- 30	- 38	- 50	- 55	- 60					
17	·30	·30	·30	·30	·30	·30	·30	·30	·30	·30	699	191	24	328	136
	29	51	22	- 4	- 12	- 31	- 40	- 45	- 50	- 57					
18	·20	·20	·25	·33	·42	·50	·60	·60	·60	·40	794	96	3	360	218
	20	21	- 7	- 19	- 41	- 52	- 50	- 41	- 24	- 26					

surface, was estimated without any reference to Stefan's constant as ranging from a small amount for a cloudy sky to an average of 200 for a clear sky. By Mr. Richardson's method, omitting the improbable case of $\eta = \cdot 10$, the range is from 55 to 220, a good agreement.

F + K is the total loss of the earth's heat and is equal to such part of the sun's heat as is not reflected. Abbot and Fowle give the mean value for the earth as about 430. Here again there is good agreement.

It is noteworthy that whichever distribution of η be taken the value of F, the calculated upward radiation of the atmosphere itself remains almost unaltered at about 320 g.c. The maximum value is 354, and two distributions only, both of which assign impossibly high values to η in the upper strata, have values notably below 300. There seems good ground, therefore, for taking 320 g.c. per day as within 10 per cent of the average outward radiation of the atmosphere over England. It is equivalent to the full radiation of a black body at 232° a. If we include K so as to have the whole radiant energy given out by the earth, including the atmosphere, the equivalent temperature is 247° a.

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The results given above refer to the special arrangement of temperature that prevails over England or Europe at about the same latitude.

With different temperatures the results would be different, and the cases of a cyclone and anticyclone in England, together with three cases for the equatorial distribution of temperature, have been worked out. Between the cyclone and anticyclone it appears that more heat is being lost by radiation in the cyclone than in the anticyclone, but we cannot say that more is being supplied, because the conditions are only temporary and not like the mean values permanent.

The tropical values differ from those for this latitude inasmuch as the highest layers are all accumulating heat by long wave radiation. This is due to the fact that owing to their low temperature they are giving out very little, and it confirms the belief I have long held that the low temperature is due to dynamic and not to radiative causes.

The following six curves have been drawn; A to D refer to average conditions in England, E and F to the equator. The ordinates represent the pressure beginning with 1000 mb. and falling to 0 at the top. The abscissae represent the number of degrees C. that the air at any point would rise or fall in one day under the influence of long wave radiation alone, a point on the left of the line of reference denoting a cooling. The curves are smoothed and refer to general conditions rather than any special distribution of η.

A. Clear dry air with low power of absorption throughout.
B. Air with high power of absorption throughout.
C. Clear air throughout, but power of absorption increasing decidedly towards the bottom.
D. Heavy clouds in the lower part of the atmosphere but not in the first kilometre, clear above.
E. Tropics. Uniform but moderate power of absorption throughout.
F. Tropics. Otherwise the same as D.

There is great similarity about all the curves, excepting that the two representing the tropics have no part on the left at the top. In thickly clouded skies the maximum loss by radiation occurs at 4 or 5 k. height. For clear skies the loss of heat is about the same for the first 3 k. and amounts to rather over 1°·5 C. per day. It can readily be made good by the condensation of vapour, but there are regions where and periods in most places when rain does not fall for a month, and yet in such cases so far as we know no fall of temperature occurs. These regions are anticyclonic regions and the loss of heat is probably made good by slowly descending air.

A few words must be said about the validity of the assumptions on which Mr. Richardson's method of calculation is based. There are two points that may modify the conclusions reached, but I do not think they do so to any serious extent. The absorbing power of the air may be selective, that is to say certain wave lengths may pass through readily while others are completely absorbed. This should not greatly matter so far as the mutual radiation between layer and layer of the atmosphere is concerned, because by Kirchhoff's law each layer will be able to absorb just those wave lengths which it, and therefore to a great extent its neighbouring layers, can emit. But the case is different

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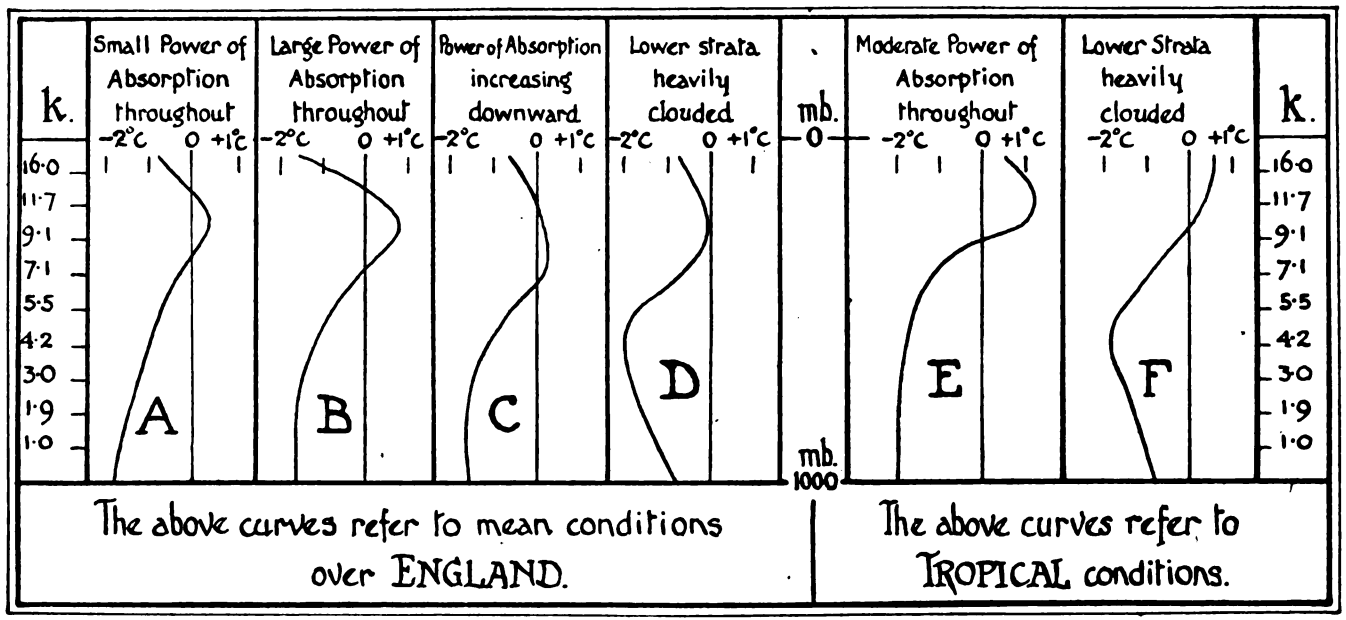

FIG. 1.—Curves showing the approximate amount that the air at any height will rise or fall in temperature per day under the action of long wave radiation. The curves have been obtained by dividing the atmosphere into ten equal parts and calculating on an arbitrary assumption of its emissive and absorptive power the radiation to and from each stratum. Where the curve is to the left of the vertical line it denotes that the air is losing heat by radiation at the rate per day shown on the scale above the curve. Solar radiation is not taken into account.

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with the earth's radiation which has been assumed, probably correctly, to be nearly that of a black body. If the absorbing power of the atmosphere be selective, the lower layers of the atmosphere have the pick so to speak of the terrestrial radiation, just as the upper layers have of the solar, and consequently various values of η would have to be applied to the different strata for the earth's radiation, and yet another value for radiation from the atmosphere. That this is to some extent the case has been proved by F. E. Fowle in a valuable paper.[1] The other point is that I think some part of the earth's radiation is reflected back to the earth. A considerable part of the sun's radiation is scattered and sent back to space, and remembering the frequency of clouds it seems reasonable to suppose that the same thing happens to some of the long wave radiation from the earth. The case can be met in the calculation by ascribing a lower temperature to the surface of the earth, since the return to the earth of some of its own radiation is equivalent, save to the lower strata through which the reflected radiation twice passes, to a smaller output.

The general effect of ascribing a lower temperature to the earth is to increase the calculated loss of heat in the lower strata of the air, but to leave the figures relating to the upper strata very little altered. The natural effect is to increase the total radiative loss of the lower strata and therefore increase the calculated value of L + C, thus bringing it into closer accordance with the value 260 g.c., which other considerations suggest.

In view of these two considerations, more particularly in view of the selective absorption of the atmosphere, I am somewhat doubtful if these results are worth publishing, but am encouraged to do so by the good agreement of the values obtained with those deduced by other means.

A correct knowledge of the vertical flow of heat in the atmosphere by radiation and other processes is very important for an advance in theoretical and ultimately in practical meteorology, but the subject is very difficult and complicated. We are only concerned with the vertical component, but the actual radiation is occurring in every direction. Also the experimental difficulties in the way of determining the constants are very great, as the instruments required are delicate and expensive, and the values obtained by different workers are not as consistent as could be wished.

DISCUSSION.

Lieut.-Col. GOLD, in welcoming this contribution to the theory of atmospheric radiation, said that he had been led to consider the subject some twelve years ago primarily because radiation furnished the key to a rational explanation of the Isothermal Layer or Stratosphere. He found, as Mr. Richardson had done, that the best way of dealing with the problem was to divide the atmosphere into a series of horizontal layers, not of equal thickness, but of equal mass; or, what came to the same thing, layers such that the decrease of pressure from the bottom to the top was the same for each layer. That was not merely the best

[1] "Water-Vapour Transparency to Low-Temperature Radiation," *Washington, D.C., Smithsonian Inst. Misc. Collect.*, **68**, No. 8 [1918].

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way, but the only way which permitted the rather complicated integrals to be evaluated.

In Mr. Dines's presentation it appeared to be assumed that η was the same for the radiation from the layer and for the absorption by it: that assumption was not self-evident and required justification, because the radiation entering a layer at an inclination to the vertical was not the same as the radiation entering it in a vertical direction; and the absorbing power of the layer for inclined radiation was greater than its absorbing power for vertical radiation. He would also have liked to see the results of the computation in Table I. for values of η 10 or 100 times as great for the lowest layer as for the topmost layers: there was little doubt that the value of η depended very largely on the amount of water vapour present; and this amount was normally very much greater in the layers near the bottom than in the upper layers. Ozone in the upper layers might compensate to some extent, but the effectiveness of ozone as an absorber was, he believed, more marked for solar radiation than for atmospheric radiation owing to the difference in wave-length of the predominating radiation in the two cases. For an atmosphere of uniform constitution, *i.e.* for η the same for all layers, he had found that a rate of fall of temperature of rather less than the adiabatic rate for dry air could not be maintained higher than the 5th of Mr. Dines's 10 layers. If the upper layers were cooled below the temperature at the top of the 5th layer they would absorb more radiation than they emitted, and on this account their temperature would rise again.

Finally, the radiation (atmospheric and terrestrial) passing upward through the top layer must balance the net amount of incoming solar radiation, *i.e.* the total solar radiation minus the solar radiation reflected or diffused to space. He estimated this net amount to be about 40 per cent of the total.

With regard to the value of η for clouds, this ought to be high. The experimental investigations of the absorbing power of water vapour showed that this was very marked in the wave-lengths for which terrestrial radiation had its highest intensity. The deductions from the consideration of the comparatively high temperature radiation of lighthouses ought to be applied with much hesitation to the low temperature radiation of the atmosphere. There were certainly occasions when the radiation from a cloud layer above freezing point was sufficient to prevent air at a temperature below freezing point maintaining frost on the ground; and if the clouds were good radiators they must also be good absorbers. Finally, convection must always carry heat upwards and not downwards in the atmosphere in so far as the convection arose from thermal causes. Dynamic causes, such as eddies, acted in the reverse direction; but the effectiveness of eddies in the stratosphere or in any layers where the gradient of temperature is much below the adiabatic gradient is unlikely to be of the same order as the effectiveness of radiation.

Sir Napier Shaw said that to have got out a definite estimate of the way the atmosphere is cooling or getting warm in consequence of the terrestrial radiation was a great step towards arriving at the process by which atmospheric changes were brought about. Mr. Dines suggested that where the curve of heat-transference was on the left-hand side and the atmosphere was in consequence losing heat, heat must be supplied to it by the sun or in some other way, because the temperature of the atmosphere must be made up; in other words, if there was loss by terrestrial radiation there must be equal gain from some other source. He wondered whether Mr. Dines sufficiently regarded the atmosphere as a "going concern." Suppose air was going, say, northwards while it was cooling at the rate of 2° in 24 hours. At the end of 24 hours it might be at a place which was normally 2° colder than the starting point and in its new position it would not be out of place. He wondered, therefore, whether

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Mr. Dines's diagram indicated that the proper limbo for air losing heat, which apparently belonged to the troposphere, was towards the north, where on the average the lower air was colder, and towards the south in those higher regions where the normal gradient of temperature was reversed.

Mr. L. F. RICHARDSON said that the astonishing thing about Mr. Dines's diagrams was that the result came out the same in spite of the variety of assumptions that he made for η in the stratum. Personally he had begun the study of atmospheric radiation with Col. Gold's paper on the stratosphere, but finding that rather a difficult text-book he contrived the method of dividing the sky into six equiangular zones and the atmosphere into ten layers of equal mass and treating the problem by arithmetic. By applying this to Angström's observations, made on the top of Mount Whitney in California on a particularly dry night, he had got a certain coefficient η. Then it was noticed that the work could be simplified by lumping all the zones together and making a suitable adjustment to η.

Mr. W. H. DINES, in reply to Lieut.-Col. Gold, said he was quite aware of the difficulty with regard to the radiation being in all directions and not only vertical, but it seemed to him that the emissive and absorbing power of a layer would be equal, for while it was true that more would be absorbed from an inclined than from a vertical ray it was equally true that a layer would give out more in the inclined direction; in fact, as the radiation approached the horizontal direction it approached in amount the value due to a full radiator at the same temperature. He would follow out Col. Gold's suggestion and work out some results with very small values of η in the upper strata. His (Mr. Dines's) analysis showed that the 6th and 7th strata were absorbing by radiation more heat than they were giving out, this result agreeing with Col. Gold's, but his (Mr. Dines's) explanation was that these strata were passing heat downwards by the process of mixing which cooled the upper strata and were thus disposing of their excess. He agreed that one could not be positive without experimental evidence that fog was more pervious to long than to short wave radiation, but it seemed likely that as the wave-length approached or even exceeded the diameter of the fog particles the waves would get through more easily.

Convection could not occur until an adiabatic lapse rate was established, and he thought that the result of mixing, in which he included convection, must be to establish such a lapse rate. Now such a lapse rate did not exist except for short periods and in small patches of the atmosphere. The only process capable of opposing the formation of an adiabatic lapse rate seemed to him to be radiation, and hence he looked upon mixing and radiation as two opposing forces which just counterbalanced each other.

In reply to Sir Napier Shaw he said he did not think a prevailing South wind component in the troposphere with a return above supplied the heat lost by radiation in the lower strata. It was true that there was a horizontal temperature gradient of about 1°C. per two degrees of latitude reversed above, but then the correlation between wind direction and temperature was small, and there was no difficulty in supposing the radiative loss to be made good by the latent heat of condensation in the lower strata.

In reply to Mr. Richardson he said the fact that the values ascribed to η did not seriously alter the final result was easily explained, for if the value of η for any given stratum was increased the amount of radiation emerging on the other side was decreased, but the loss was very largely compensated by the increased radiation given out by the stratum itself.

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The Meteorological Service of Rio Grande do Sul, Brazil.

(Porto Alegre, Brazil, Inst. Astr. e Met. da Escola de Engen. *Dados Meteorologicos*, 1915 ; 1916. Porto Alegre, 1917 ; 1918. fo. 1915, pp. 77, pls. 2 ; 1916, pp. 74, pls. 2.)

The meteorological service of the State of Rio Grande do Sul was established in 1915, and two volumes dealing with the results obtained have been published. At Porto Alegre, the seat of Government of the State (lat. 30°4′ S., long. 51°8′ W.), there is a first-class observatory established in December 1909, where hourly observations are maintained. The town, which contains about 100,000 inhabitants, of whom about 15,000 are Germans or of German origin, is situated at the northern extremity of Lagoa dos Patos, the largest lake in Brazil, and is the distributing centre for the agricultural products of the State, which covers an area of 91,000 square miles, somewhat larger than Great Britain.

The climatic data for Porto Alegre are very comprehensive, daily means being published, as well as the means of the principal climatic elements observed under each wind direction. Complete details filling 48 columns are given for each of the eleven stations of the second order where observations are made at 7, 14, and 21 hours. There are also twenty-three stations described as of the third class. In the report for 1916 there seems to be no difference between the two classes of stations, but in the 1915 report the afternoon observation was omitted at stations of the lower category. Small maps are given in each report showing isothermals and isohyetals for each month over the State which are discussed at length in the text. Full-page maps show the annual distribution of temperature and rainfall. The representation is very good, as each complete single degree land square of latitude and longitude has from one to four stations. The stations range in latitude from M. Ramos in 27°27′ S. to Santa Victoria in 33°31′ S., and in longitude from 49° W. to 57°20′ W. Twelve of the stations are situated at heights less than 100 metres, and there are eight at heights over 500 metres. The highest station, Vaccaria, is 955 metres (3133 feet) above sea-level. Observations began as stated at Porto Alegre in December 1909, while eleven others commenced at the beginning of 1912, so that in a few years fairly good normals should be available.

In 1915 the average duration of bright sunshine over the whole state (9 stations) was 53 per cent of the possible, and in 1916 (10 stations) 57 per cent, so that sunshine is abundant. The extreme temperatures recorded in the two years under notice were 40° C. (104° F.) and −7°·5 C. (18° F.). Frost is fairly common in winter, and at Vaccaria snow fell on July 4 and 22, 1916.

The wettest district in both years was the square between latitudes 29° S. and 30° S., longitudes 50° and 51° W., with a rainfall over 3000 mm. (118 inches) in 1915, and 2500 mm. (98 inches) in 1916. Coast stations in the south had about 1250 mm. (49 inches) in 1915, and about 1000 mm. (39 inches) in 1916. The wet area where the elevation is considerable had naturally the lowest temperature, 14° to 15° C. (57° to 59° F.) in both years, while the highest mean annual temperature in 1915 was 19° C. (66° F.) close to the Argentine boundary, and in 1916 the highest isotherm of 18° C. (64°·4 F.) ran along the 30th parallel.

Reports like those under notice are very welcome, and it is to be hoped that other Brazilian states, following the example of Rio Grande do Sul, Minas Geraes and Saõ Paulo, will publish their detailed results in similar form, and thus supplement the less complete—although as far as it goes useful—information supplied by the Federal Service in the *Annuarios* of the Rio Observatory. R. C. M.

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INTERNAL FRICTION IN THE ATMOSPHERE.

By D. BRUNT, M.A., B.Sc., F.R.Met.Soc.

[Received May 5, 1919—Read February 18, 1920.]

1. *The Equations of Motion.*—The frictional force acting upon any element of volume of the atmosphere has the effect of causing a loss of horizontal momentum, and the force may be measured by the amount of horizontal momentum lost per unit of time. The vertical transference of momentum is chiefly brought about by the eddies which form in the earth's atmosphere, and Taylor[1] has given a simple formula for computing the rate at which this transference takes place. If u and v be the components of wind velocity along any two perpendicular axes x, y, in the horizontal plane, then the rates of loss of momentum parallel to these axes are $K\rho\delta^2u/\delta z^2$ and $K\rho\delta^2v/\delta z^2$ respectively, where K is the coefficient of eddy-diffusion, and ρ the density of the air.[2] If then we represent the frictional force acting on unit volume by R, it being understood that R is a function of the height z, both as regards its magnitude and its direction, then the components of R along the axes of x and y are $K\rho\delta^2u/\delta z^2$ and $K\rho\delta^2v/\delta z^2$. So far the results are independent of the direction of the axes, but it will be found convenient in the later stages to take the axis of x tangential to the isobar at M.S.L., and the axis of y perpendicular to it, in the direction of decreasing pressure.

A considerable simplification of the equations can be effected by using a vectorial notation, representing the horizontal velocity at any height by V. With the usual convention we may write $V = u + iv$. Then R can be represented vectorially by $K\rho\delta^2V/\delta z^2$.

We are now in a position to write down the forces acting on an element of air at any height. In the figure below, let the axes Ox, Oy be drawn parallel to the isobar and perpendicular to the isobar, respectively, the point O being at any height z above the ground. Let G be the magnitude of the gradient wind, directed along Ox, and let V be represented by OP. At the ground, OP will make an angle α with Ox. Let the frictional force R on unit volume of air at O be represented by OS, making an angle β with the reversed wind-direction. Draw OQ perpendicular to OP. Further, let ϕ be the latitude of O, and ω the angular velocity of rotation of the earth.

The pressure-gradient acting along Oy is $2\omega\rho \sin\phi \,.\, G$. The rotation of the earth produces a deviating force $2\omega\rho \sin\phi \,.\, V$ along OQ. The forces in the plane xy acting on unit volume of air at O may therefore be written

$$\left.\begin{aligned} &2\omega\rho \sin\phi \,.\, G \text{ along } Oy \\ &2\omega\rho \sin\phi \,.\, V \text{ along } OQ \\ &R \text{ along } OS \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (1)$$

These may be written vectorially in the form

$$2\omega\rho \sin\phi \,.\, iG, \quad -2\omega\rho \sin\phi \,.\, iV, \text{ and } K\rho\delta^2V/\delta z^2.$$

[1] Taylor, G. I., "Eddy Motion in the Atmosphere," *London, Phil. Trans. R. Soc.*, **215** (Ser. A), 1915, p. 1.

[2] In the derivation of this relation, air is treated as an incompressible fluid.

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For air in steady motion these forces must be in equilibrium, and their algebraic sum must be zero. This condition reduces to

$$K\rho\frac{\delta^2 V}{\delta z^2} - 2\omega\rho \sin\phi \,.\, i(V - G) = 0.$$

Substituting $B^2 = \omega \sin\phi/K$ we may write this equation in the form

$$\frac{\delta^2 V}{\delta z^2} - 2iB^2(V - G) = 0$$

or

$$\frac{\delta^2 V}{\delta z^2} - (1 + i)^2 B^2 (V - G) = 0. \quad . \quad . \quad . \quad . \quad (2)$$

It should be noted that the only assumption made hitherto is that R can be represented by $K\rho\delta^2 V/\delta z^2$. In deriving equation (2) no assumption has been made as to the constancy of B or of G. In order to reduce it to an integrable form, we shall assume that B is constant and G either constant or a linear function of the height z. The solution of equation (2) is then

$$V - G = C_1 e^{(1+i)Bz} + C_2 e^{-(1+i)Bz}. \quad . \quad . \quad . \quad . \quad (3)$$

Since we cannot admit infinite values of V for infinite values of z, we must have $C_1 = 0$.

$$V - G = C_2 e^{-(1+i)Bz}$$
$$= Ce^{-(1+i)Bz+i\gamma}, \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where C and γ are both real constants, whose values must be determined from the boundary conditions. We assume, with Taylor, that the boundary condition at the ground is that the direction of slipping is in the direction of strain. In terms of equation (4) this means that for $z = 0$ $\delta V/\delta z$ is in the same direction as V. Let α be the angle between the surface wind and the gradient wind. Then for $z = 0$, $\delta V/\delta z$ must make an angle α with the gradient wind. Differentiating equation (4) we find at $z = 0$

$$\frac{\delta V}{\delta z} = -CB(1 + i)e^{i\gamma}$$
$$= \sqrt{2}CBe^{i(\gamma+\frac{5\pi}{4})}, \quad . \quad . \quad . \quad . \quad . \quad (5)$$

since $1 + i = \sqrt{2}e^{i\frac{\pi}{4}}$ and $-1 = e^{i\pi}$.

But since $\delta V/\delta z$ makes an angle α with the real axis, for $z = 0$, it is possible to write

$$\frac{\delta V}{\delta z} = De^{i\alpha}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Equations (5) and (6) are identical, and so

$$\gamma + \frac{5\pi}{4} = \alpha \text{ or } \gamma = \alpha - \frac{5\pi}{4}.$$

Substituting in (4),

$$V - G = Ce^{-Bz+i(\alpha-\frac{5\pi}{4}-Bz)}. \quad . \quad . \quad . \quad . \quad (7)$$

To evaluate C we use the condition that for $z = 0$, V makes an angle α with the axis of x. Since

$$V = G - C\cos(\alpha - \tfrac{\pi}{4}) - iC\sin(\alpha - \tfrac{\pi}{4})$$

must be identical with

$$V = M\cos\alpha + iM\sin\alpha,$$

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the condition reduces to

$$\frac{-G+C\cos(\alpha-\frac{\pi}{4})}{\cos\alpha}=\frac{C\sin(\alpha-\frac{\pi}{4})}{\sin\alpha}$$

$$G\sin\alpha=C\sin\tfrac{\pi}{4},\quad\text{or } C=\sqrt{2}G\sin\alpha=-\sqrt{2}G\sin\alpha.e^{i\pi}.$$

Equation (7) therefore becomes

$$V=G+\sqrt{2}G\sin\alpha.e^{-Bz+i(\alpha+\frac{3\pi}{4}-Bz)}. \quad . \quad . \quad . \quad (8)$$

Thus the wind V at any height is equivalent to the gradient wind together with an added component of magnitude $\sqrt{2}G\sin\alpha.e^{-Bz}$, acting at an angle $\alpha+\frac{3\pi}{4}-Bz$ with the direction of the gradient wind. This second component decreases with height according to the exponential law, and its direction rotates uniformly counter-clockwise with increasing height. It follows that if in the figure previously described we draw vectors OP to denote the wind at different heights, these vectors will sweep out an equiangular spiral, if G is constant.[1]

If we return to our original notation and write $V=u+iv$, we find from equation (8)

$$\left.\begin{aligned} u-G&=\sqrt{2}G\sin\alpha.e^{-Bz}\cos(\alpha+\tfrac{3\pi}{4}-Bz)\\ &=-\sqrt{2}G\sin\alpha.e^{-Bz}\cos(\alpha-\tfrac{\pi}{4}-Bz).\\ v&=\sqrt{2}G\sin\alpha.e^{-Bz}\sin(\alpha+\tfrac{3\pi}{4}-Bz)\\ &=\sqrt{2}G\sin\alpha.e^{-Bz}\sin(\alpha-\tfrac{\pi}{4}-Bz).\end{aligned}\right\} \quad . \quad (9)$$

These equations are equivalent to those derived by Taylor (*loc. cit.*).

2. *The Frictional Forces.*—The frictional force per unit volume, R, must not be confused with the frictional force acting upon unit surface, which Taylor denotes by F. The relationship between R and F is easily derived. Consider a small horizontal disc of area A, and thickness dz, with its base at height z. If F_x, F_y be the components parallel to the axes of x and y of the skin friction acting upon unit area of the base, then

$$F_x=-K\rho\frac{\delta u}{\delta z},\qquad F_y=-K\rho\frac{\delta v}{\delta z},$$

$$F=F_x+iF_y=-K\rho\frac{\delta V}{\delta z}.$$

The friction on the upper surface will be $-(F+dF)$ or $-(F+\delta F/\delta z.dz)$, and the resultant force on the whole disc will be $-\frac{\delta F}{\delta z}.A dz$, or $-\frac{\delta F}{\delta z}$ per unit volume. Hence

$$R=-\frac{\delta F}{\delta z}=K\rho\frac{\delta^2 V}{\delta z^2}. \quad . \quad . \quad . \quad . \quad (10)$$

Differentiating equation (8), and remembering that $1+i=\sqrt{2}e^{\frac{i\pi}{4}}$, we find

$$\left.\begin{aligned} F&=2K\rho BG\sin\alpha e^{-Bz+i(\alpha+\pi-Bz)}\\ R&=2\sqrt{2}KB^2\rho G\sin\alpha e^{-Bz+i(\alpha+\frac{5\pi}{4}-Bz)}\end{aligned}\right\} \quad . \quad . \quad (11)$$

[1] This spiral was discussed by Hesselberg and Sverdrup in *Beitr. Physik Atmosph., Leipzig*, 7, 1916, p. 156, where a comparison with observations is shown.

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Since $KB^2 = \omega \sin \phi$, the second equation reduces to

$$R = 2\sqrt{2}\rho\omega \sin \phi \,.\, G \sin \alpha e^{-Bz+i(\alpha+\frac{5\pi}{4}-Bz)}. \quad . \quad . \quad (12)$$

At the ground R depends only on G and α, and does not explicitly involve K, but as the value of α is determined by the values of G and K, it follows that R is not independent of the value of K.

From equations (11) we immediately derive $R = \sqrt{2}B \,.\, Fe^{\frac{i\pi}{4}}$, showing that R always acts at an angle of $\pi/4$ with the direction of F. At the ground F is parallel to the reversed wind direction, so that R at the ground must act at an angle $\pi/4$ with the reversed wind direction. We may contrast with this the assumption of Guldberg and Mohn [1] that R is directly opposed to the wind direction. The angle between R and V affords a very effective method of testing the theory of § 1, since the magnitude and direction of R can be derived independently of any theory from the statement of the forces acting on unit volume, given in (1) above.

3. *Comparison with Observations.*—Consider the forces acting on unit volume of air near the ground. In Fig. 1, Ox is tangential to the

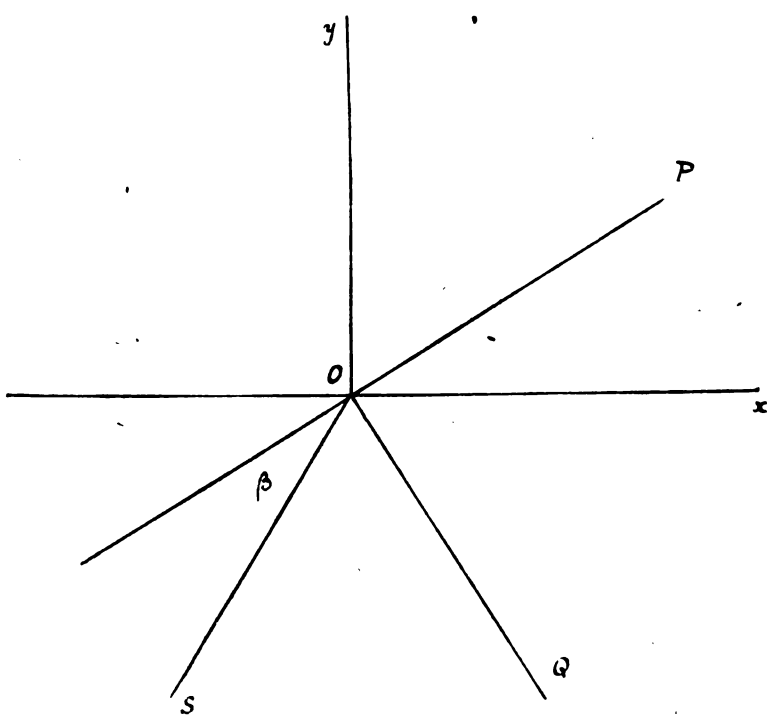

FIG. 1.

isobar, Oy is drawn perpendicular to it in the direction of decreasing pressure, OP represents the wind velocity on the ground, and the $\angle x$OP is of magnitude α. The frictional force R acts along OS, at an

[1] "Études sur les mouvements de l'atmosphère," 1re partie, Christiania, 1876.

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angle β with OP reversed. Then the forces acting on unit volume of air at O are[1]

$$\begin{aligned} & 2\omega\rho V \sin\phi \quad \text{along OQ}, \\ & 2\omega\rho G \sin\phi \quad \text{along O}y, \\ \text{and} \quad & R \quad \text{along OS}. \end{aligned}$$

Resolving along and perpendicular to OP, we find

$$\left.\begin{aligned} 2\omega\rho \sin\phi \,.\, G \sin\alpha &= R\cos\beta. \\ 2\omega\rho \sin\phi \,.\, G \cos\alpha &= R\sin\beta + 2\omega\rho \sin\phi \,.\, V. \end{aligned}\right\} \quad . \quad . \quad (13)$$

In this equation R and β are the only quantities which are not known, either from observation or measurement on a synoptic chart. When V, α, and ρ have been observed, and G computed from a chart, the two equations can be solved in a straightforward manner for R and β.

A number of continental writers have investigated the magnitudes of R and β, and we shall merely quote their results, which have been collected by Åkerblom,[2] for comparison with the theoretical value of $\pi/4$, which the theory yields for β. The table below gives the mean values of α and β, and the number of observations on which these means are based, for a number of stations.

Station.	Latitude.		α	β	Number of Observations.
Paris	49° N.	Winter	37°	46°	696
,,		Summer	30°	49°	673
O'Gyalla	48°	Winter	48°	29°	514
,,		Summer	40°	40°	429
Horns Rev	56°	Winter	16°	59°	902
,,		Summer	18°	57°	689
Magdeburg	52°	...	...	25°	...
Lindenberg	48°	...	...	28°	...
Elsfleth	53°	...	...	30°	...
Breslau	51°	...	...	34°	...
Hamburg	54°	...	...	44°	...
Königsberg	...	...	...	49°	...
U.S.A.	...	...	...	24·5°	...
Atlantic Ocean	9° to 60°	...	...	51°	237

The Paris values refer to observations made at the Bureau Central Météorologique. The mean value of β for Paris, particularly in winter, is in excellent agreement with the theoretical value, 45°, but for most of the other stations the agreement is poor. The lack of agreement with the theoretical value may be partly due to effects of topography upon the surface winds, but cannot be wholly explained in this way. Horns Rev is a lightship, 50 kilometres off the west coast of Jutland, and topographic effects should be negligible for this station. It should be added, however, that the sea-breeze showed an appreciable effect at this station. O'Gyalla is in the middle of the Hungarian Plain, away from any irregularities of level, but the mean value of β, derived from the winter observations, is only 29°. Most of the German stations yield values of β which are well below the theoretical value, as also does the mean of a number of stations in the U.S.A.

Åkerblom found that at O'Gyalla β showed a well-defined diurnal

[1] V is here the scalar wind-velocity at the ground.

[2] Åkerblom, Filip, "Über die Beziehungen zwischen Luftdrucksgradient, Wind, und Reibung bei stationärer geradliniger Bewegung," *Ark. Mat., Stockholm*, **11** (1916), No. 18.

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variation, opposite in phase to that of α. The values of α and β which he quotes are very closely represented by the linear equation

$$\beta = 0{\cdot}7\ (90^\circ - \alpha),$$

whereas theory demands that β should be constant at all times, and independent of the value of α.

The final result of the comparison of theory with observation is to show that, even when means of many hundreds of observations are taken, the values of β fail to agree with the values predicted by the theory. It remains to consider where the theoretical discussion is likely to be false. The statement of forces in equilibrium enunciated in (1), and the subsequent derivation of equation (2), are based on the assumption of steady motion, and so the theoretical value $\beta = 45^\circ$ only holds for steady motion. It seems justifiable to assume that when the means of a large number of observations are taken, the resultant mean value of β corresponds to a steady state of motion and an unchanging pressure distribution. And so we may assume that the discrepancy is not due to the assumption of a steady state of motion.

In order to reduce equation (2) to a tractable form, it was assumed that both B and G do not vary with height. If either or both of these quantities varies with z, the form of the solution of equation (2) is changed and the value of β predicted by the theory will generally differ from 45°. It is generally assumed that G does not vary with height, and it is probably justifiable to assume that the means of a large number of observations will correspond to a value of G not varying appreciably with height. There remains as the probable cause of the discrepancy between theory and observations the assumption that B is constant at all heights. This assumption was made in order to facilitate the integration of equation (2), but it now appears that this assumption is definitely false.

The necessary and sufficient condition that β as deduced from equations (13) should be 45° is easily seen to be

$$V = G\ (\cos\alpha - \sin\alpha). \quad . \quad . \quad . \quad (14)$$

This holds independently of any theory. If this equation is not satisfied, the value of β derived from equations (13) will differ from 45°. It was found that the values of V, G, and α, for Paris, satisfied this equation, while those for O'Gyalla and Horns Rev did not satisfy this equation even approximately. Equation (14) demands that α should be less than 45°, but the mean values of α at O'Gyalla exceeded 45° in winter.

It should be noted that equation (14) was derived by Taylor on the assumption that B, and therefore K, does not vary with height. The failure of this equation to fit the mean of a large number of observations is in itself an indication that there is some false assumption behind the derivation of Taylor's equations.

4. *Evaluation of K.*—Although some evidence has been adduced to show that K is not constant with height, it may be of interest to apply equation (12) to evaluate K, it being assumed that K is constant from the ground up to the level of the Eiffel Tower. In order to compare these with values derived from the same data by a different method, a brief account is given of Åkerblom's calculation of $K\rho$, from a

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comparison of the magnitude and direction of the wind at the top of the Eiffel Tower and at the ground.[1]

Åkerblom assumed that the pressure gradient remained constant in magnitude, but changed its direction, with height, the angle between the gradient at a height z and the gradient at the ground being mz, where m is a constant to be determined from the observations. The components of velocity along the axes x and y corresponding to this assumption are

$$\left.\begin{aligned} u &= \mathrm{G}\cos\gamma\cos(mz+\gamma) + \mathrm{D}e^{-\mathrm{B}z}\sin(b+\mathrm{B}z) \\ v &= \mathrm{G}\cos\gamma\sin(mz+\gamma) + \mathrm{D}e^{-\mathrm{B}z}\cos(b+\mathrm{B}z) \end{aligned}\right\} \quad . \quad . \quad (15)$$

B and G have the same interpretation as in the earlier portions of the present paper, while γ is given by

$$\tan\gamma = \frac{m^2}{2\mathrm{B}^2} = \frac{m^2\mathrm{K}}{2\omega\sin\phi}. \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Let h be the height of the layer considered (= 286 metres), and let suffixes 0 and 1 indicate values at the top and bottom of the layer. Further let

$$\left.\begin{aligned} u - \mathrm{G}\cos\gamma\cos(mz+\gamma) &= \bar{u} \\ v - \mathrm{G}\cos\gamma\sin(mz+\gamma) &= \bar{v} \end{aligned}\right\}. \quad . \quad . \quad . \quad (17)$$

Then from equations (15) and (17)

$$\bar{u}_0 = \mathrm{D}\sin b, \qquad \bar{v}_0 = \mathrm{D}\cos b, \quad . \quad . \quad . \quad (18)$$

$$\bar{u}_1 = \mathrm{D}e^{-\mathrm{B}h}\sin(b+\mathrm{B}h), \qquad \bar{v}_1 = \mathrm{D}e^{-\mathrm{B}h}\cos(b+\mathrm{B}h). \quad . \quad (19)$$

From these equations we find

$$e^{2\mathrm{B}h} = \frac{\bar{u}_0^2+\bar{v}_0^2}{\bar{u}_1^2+\bar{v}_1^2}. \quad . \quad . \quad . \quad . \quad . \quad (20)$$

Also since $$\tan b = \frac{\bar{u}_0}{\bar{v}_0}, \text{ and } \tan(b+\mathrm{B}h) = \frac{\bar{u}_1}{\bar{v}_1}, \quad . \quad . \quad . \quad (21)$$

$$\tan \mathrm{B}h = \frac{\frac{\bar{u}_1}{\bar{v}_1} - \frac{\bar{u}_0}{\bar{v}_0}}{1+\frac{\bar{u}_1\bar{u}_0}{\bar{v}_1\bar{v}_0}}. \quad . \quad . \quad . \quad . \quad (22)$$

Åkerblom uses equations (20) and (22) in turn to evaluate a constant η, which is equal to $\mathrm{K}\rho$ in our notation. A value is first assumed for m, and any value η' assumed for η. The value of γ is evaluated from (16) and substituted in (17), giving $\bar{u}_0$, $\bar{v}_0$, $\bar{u}_1$, $\bar{v}_1$, and by substitution of these values in (20) a new value η'' is derived for η. In general η'' differs from η', and the process is continued until by trial and error we obtain $\eta'' = \eta'$. This gives the value of η corresponding to the value of m with which we started. The calculation is repeated for a series of values of m. Then a similar series of pairs of corresponding values of m and η is derived by the use of equation (22). When the two series of values of m and η are represented graphically they yield two curves whose intersection gives the final values of m and η.

Åkerblom obtained negligibly small values of m, corresponding to a gradient constant in magnitude and direction, while he obtained values

[1] Åkerblom, Filip, "Recherches sur les courants les plus bas de l'atmosphère au-dessus de Paris," *Upsala, Soc. Scient. Acta*, **2** (ser. iv.), 1908, No. 2.

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of η corresponding to $K = 6{\cdot}5.10^4$ during the winter, and $K = 9{\cdot}23.10^4$ for the summer.

If the gradient be assumed constant in magnitude and direction at all heights, equation (8) will hold for R. In the paper referred to above, Åkerblom gives the first four columns of the table below, where β_0 is the angle between the frictional force R_0 at the ground and the surface wind, and β_1 the angle between the frictional force R_1 at the top of the Eiffel Tower and the wind at that level.

	R_0.	R_1.	β_0.	β_1.	$\beta_0-\beta_1$.	$\beta_0-\beta_1+15°$.	Bh.	$\frac{R_0}{R_1}$.	Bh.
Winter .	128.10^{-5}	56.10^{-5}	46°	13°	33°	48°	·84	2·3	·81
Summer .	86.10^{-5}	43.10^{-5}	49°	24°	25°	40°	·70	2·0	·70
Mean .	108.10^{-5}	48.10^{-5}	47°	17°	30°	45°	·79	2·25	·77

The mean deviation of the wind at the top of the Tower from that at the ground is 15°, and thus $\beta_0 - \beta_1 + 15°$ is the mean deviation of the direction of R_1 from that of R_0. Equation (8) shows that this deviation is Bh. The seventh column of figures gives the value of Bh obtained by converting $\beta_0 - \beta_1 + 15°$ into radians. Equation (8) also shows that $R_0/R_1 = e^{Bh}$, and the last column of the table gives the values of Bh derived from this relation. Taking the mean of the two columns headed Bh, and substituting $h = 28600$ cm., and $K = \omega \sin \phi / B^2$, we obtain the values $K = 6{\cdot}8.10^4$ in winter, and $K = 9{\cdot}3.10^4$ in summer.

The closeness of these values of K to those deduced by Åkerblom from a consideration of the changes in magnitude and direction of the wind from the base to the top of the Eiffel Tower appears to support the assumptions underlying the mathematical treatment, but it must be remembered that when $M = 0$ Åkerblom's equations of motion reduce to equation (8) above. It should be noted that the values of Bh in the last column, and in the last column but two of the table above, are in close agreement. The values derived for K compare very favourably with the mean value of K (10.10^4), derived by Taylor [1] from temperature observations on the Eiffel Tower. A value of the same order of magnitude was deduced by Hesselberg and Sverdrup [2] from a discussion of pilot balloon observations at Lindenberg ($K = 5.10^4$).

The value R has frequently been assumed to be directly proportional to V. Åkerblom, in his discussion of the lower currents over Paris, quotes some figures which appear to bear this out. It is interesting to follow this out in terms of the equations derived above. We found that R depends only on the value of $G \sin \alpha$, all the other factors being mere numerical constants. Now Taylor [3] found that over grassy land like Salisbury Plain, the frictional force F may be represented by $0{\cdot}0023\rho V^2$. Referring back to equations (11) we find that [4] when $2 = 0$

$$\frac{F}{\rho} = 2KBG \sin \alpha = 0{\cdot}0023\ V^2. \quad . \quad . \quad . \quad (23)$$

[1] *London, Proc. R. Soc.*, **94** (ser. A), 1917, p. 141.
[2] *loc. cit.*
[3] *London, Proc. R. Soc.*, **92** (ser. A), 1916, p. 196.
[4] Note that this equation is wrongly quoted as

$$\frac{F}{\rho} = 0{\cdot}0023\ V^2 = 2KG \sin \alpha / B$$

in Taylor's paper, *Proc. R. Soc.*, **94**, 1917, p. 149, equation (5), but Taylor's subsequent equations are correct.

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It follows that when $z = 0$

$$R = 2\sqrt{2}\ \rho\omega \sin\phi\,.\,G \sin a.$$
$$= 2\sqrt{2}\ \rho\omega \sin\phi\,.\,\frac{0{\cdot}0023\,V^2}{2KB}.$$
$$= 0{\cdot}0023 \times \sqrt{2} \times \rho V^2 B.$$
$$R = 0{\cdot}0032\rho B V^2. \quad . \quad . \quad . \quad . \quad . \quad (24)$$

If we accept Åkerblom's conclusion that R is directly proportional to V, it follows that BV is constant, or

$$B \propto V^{-1}.$$
$$K \propto V^2.$$

[*Note added February 5th.*]

In the solution of equation (2) above, it has been assumed that B is constant, mainly for the sake of obtaining a simple solution of this equation. If B is a function of z the solution in the general case is difficult, if not impossible. There are, however, two special cases in which the solution is easily obtained, viz. when B varies inversely as z or z^2.

(*a*) Let $B = \frac{c}{z}$, and write $V - G = y$.

Then as long as G is constant or a linear function of z, equation (2) may be written

$$\frac{d^2y}{dz^2} - \frac{(1+i)^2 c^2}{z^2}\,.\,y = 0.$$

Multiplying up by z^2 we obtain a homogeneous equation, whose solution is of the form Az^m. By substitution we find

$$m\,(m-1) - (1+i)^2\,c = 0.$$

Writing $m = m_0 + m_1 i$, and separating out the real and imaginary parts of the equation, we find

$$m_0^2 - m_0 - m_1^2 = 0.$$
$$2\,m_0\,m_1 - m_1 - 2c^2 = 0.$$

These equations may be solved when c is known. For present purposes it is sufficient to consider the value of m_0, which is given by

$$m_0 - \tfrac{1}{2} = \pm\sqrt{\tfrac{1}{8} + \tfrac{1}{2}\sqrt{c^2 + \tfrac{1}{16}}}.$$

The complete solution of the differential equation is then

$$y = Az^{m_0 + m_1 i} + A' z_1^{m_0' + m_1' i}.$$

If m'_0 is positive, m_0 is negative. The former is inadmissible, as it would require that the wind at great heights should tend to increase indefinitely. The only admissible solution is therefore

$$y = A\,z^{m_0 + m_1 i} = A\,z^{m_0}\,\{\cos(m_1 \log z) + i \sin(m_1 \log z)\},$$

where m_0 is negative.

In this case the relative wind V – G decreases according to a negative power of z, and the angle between it and the gradient wind direction is $m_1 \log z$. The ends of vectors OP representing the wind at different heights again sweep out an equiangular spiral, but the approach to the gradient wind is slower than in the case where B and K are constant.

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(*b*) Let $B = \frac{p}{z^2}$. Then the differential equation may be written in the form

$$\frac{d^2y}{dz^2} - \frac{2i\,p^2}{z^4}.\,y = 0, \quad \text{or} \quad \frac{d^2y}{dz^2} - \frac{p'^2}{z^4}.\,y = 0,$$

where $p' = p\,(1 + i)$.

The solution of this equation is

$$y = z\,\{Ae^{\frac{p'}{z}} + Be^{\frac{-p'}{z}}\}.$$

When z is large $e^{\frac{p'}{z}}$ and $e^{\frac{-p'}{z}}$, both tend to unity. Unless we are prepared to have the velocity increasing at great heights almost in direct proportion to the height, we must have $A + B = 0$. The last equation then becomes

$$y = Az\,(e^{\frac{p'}{z}} - e^{\frac{-p'}{z}}).$$

At great heights, where $\frac{p'}{z}$ is small, we find by expanding the exponentials,

$$y = Az\left\{\left(1 + \frac{p'}{z} + \frac{p'^2}{2!\,z^2} + \ldots\right) - \left(1 - \frac{p'}{z} + \frac{p'^2}{2!\,z^2} \ldots\right)\right\}$$

$$= Ap' = Ap\,(1 + i).$$

Hence at great heights, the velocity V approaches the value $G + Ap'$, and not the value G itself. It is not obvious why such a law of variation of eddy conductivity with height should lead to the surprising result that the limiting value of the velocity tends to some other value than the gradient wind. Further consideration of these questions must be postponed to another occasion.

It should be noted that the origin of z need not be at the ground level. If it be below ground level, this obviates any difficulty arising from infinite values of B occurring at $z = 0$.

DISCUSSION.

Mr. F. J. W. WHIPPLE said he would like to refer to the paper by V. W. Ekman[1] mentioned by Mr. Richardson at the last meeting at which this subject had been discussed. This paper was concerned primarily with ocean currents, and it was probably on that account that it had not received the attention of meteorologists, at any rate in this country, but the application of his theory to the influence of eddy-motion on atmospheric currents was explicitly made by Ekman in a footnote.[2] Mr. Whipple agreed that a complete theory should take account of the variation of turbulence with height, but he thought that the form adopted by Mr. Brunt for the equation of motion, when the eddy viscosity varied, was open to criticism.

Mr. J. S. DINES wished to know whether Mr. Brunt could give any idea as to the order of the percentage difference which might occur between the actual wind aloft and the geostrophic wind in the case referred to at the end of his paper where B varied inversely as z^2.

[1] "On the Influence of the Earth's Rotation on Ocean Currents," *Ark. Mat., Stockholm*, (1905), No. 11.

[2] *l.c.* p. 22.

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Mr. M. A. GIBLETT said that not having read all that had been written on the subject, he felt justified in asking whether opinion was unanimous in favour of the boundary condition at the surface, that the direction of motion was in the direction of the sheer, because this was intimately connected with the value of β. If the other conditions of the paper held, β might range from zero, with Guldberg and Mohn's assumption that at the surface the direction of motion was opposed to R, to 45° with Taylor's boundary condition that the air moved there in the direction of the sheer, *i.e.* that the line OP representing the wind at the surface was tangential to the equiangular spiral mentioned in the paper. An assumption outside this range, making β greater than 45°, would mean that the wind backed somewhat with increasing height before commencing to veer. The second point he intended to raise had already been mentioned by Mr. Whipple. If it was proposed to consider the coefficient K varying with height z, it seemed open to discussion as to whether $\frac{\delta}{\delta z}\left(K\rho\frac{\delta v}{\delta z}\right)$ was not a better representation of R than $K\rho\frac{\delta^2 v}{\delta z^2}$. In the first form $K\rho\frac{\delta v}{\delta z}$ represented the vertical flux of momentum, and one might obtain R by differentiating, but with the second form for R there was no convenient expression for the vertical flux.

Finally, in $\frac{\delta}{\delta z}\left(K\rho\frac{\delta v}{\delta z}\right)$ variations in ρ with height must ultimately be considered, and this suggested the possible adoption of a pressure scale for height to replace z.

Mr. D. BRUNT, in reply to Mr. J. S. Dines, said K increased upwards, and that the difference between the gradient wind and the wind attained at great heights would depend on the value of the constants p and A, and could not be estimated without first computing the values of these constants. Replying to Mr. Whipple and Mr. Giblett he said that he had put K outside the bracket in the original equation because it led to a simple solution of the equation. In reply to Mr. Giblett's first point he said that it was generally assumed that the slipping at the ground was in the direction of strain, in the work of Taylor and other writers.

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REPORT OF THE COUNCIL

FOR THE YEAR 1919.

[Submitted to the Annual General Meeting, January 21, 1920.]

THE increased interest in Meteorology engendered by the important part which the science played in the prosecution of the war has been reflected in a most gratifying manner in the prosperity of the Society. Not only does this appear in the continued growth of the Fellowship but it is also made evident by the number and high quality of the papers submitted for discussion at the meetings, the position in this respect having seldom or never been surpassed in the history of the Society. The numbers of new Fellows admitted during the past three years stand at 95, 93, and 97, so that during this period nearly 300 persons have shown their interest in the Science by joining the Society, thus very materially strengthening its position and influence. The total number of Fellows now stands at 820, and the Council confidently hope that the number may shortly reach 1000. The active co-operation of all is requested in order that this result may be brought about the more quickly.

FELLOWS.—It is with much regret that the Council have to record the loss to the Society through death of 19 Fellows, including two Honorary Members, Mr. W. G. Davis, the late distinguished head of the Argentine Meteorological Service, and General M. A. Rykatcheff. Other Fellows whose deaths have been reported during the year are :—

Col. W. F. Badgley (1889).
C. W. Bartholomew (1908).
C. H. Berners (1907).
A. Brewin (1862).
G. Burt (1903).
W. Hall (1907).
Capt. M. W. C. Hepworth (1880).
G. H. Hill (1893).
J. Hopkinson (1876).
Lt.-Col. B. F. E. Keeling (1908).
W. W. Larkin (1908).
Lt.-Col. J. McCracken (1889).
C. E. Mumford (1888).
G. C. Singleton (1919).
E. J. C. Smith (1880).
W. B. Tripp (1883).
Sir Henry Weldon (1913).

(The dates in brackets record the years of election.)

The changes in the number of Fellows are shown in the following table :—

FELLOWS.	ANNUAL.	LIFE.	HONORARY.	TOTAL.
December 31, 1918 .	636	142	15	793
Since elected . . .	+93	+4	...	+97
Reinstated	+ 2	...	...	+ 2
Deceased	− 12	− 5	− 2	− 19
Retired	− 16	...	...	− 16
Lapsed	− 12	...	...	− 12
Removed	− 25	...	...	− 25
December 31, 1919 .	666	141	13	820

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STAFF.—The release of Mr. Hampton Brown from active service in March 1919 has enabled the work of the Society to be carried on smoothly throughout the latter part of the year. In the earlier months, during the absence of Miss R. M. Davy through ill-health, it was only found possible to continue the most urgent work, and that through the kindness of Mrs. Brooks in offering her services to the Society during this difficult period

HOUSING.—A matter of great moment to the future welfare of the Society, which has been engaging the attention of the Council throughout the greater part of the year, is that of finding new premises suitable for the enlarged scope of the Society's work. The present accommodation at 70 Victoria Street has for some time past been inadequate for the proper housing of the library and the holding of the ordinary Meetings. A substantial increment in the rent demanded by the landlords from January 1, 1920, brought this question prominently forward, since the Council did not feel that they could recommend a continuance of the present tenancy under the new terms except for such period as might be necessary in order to find new and more suitable premises. With the present dearth of housing accommodation the matter was one of considerable difficulty, but arrangements have now been almost completed for the occupation of three floors of a large and commodious house at 38 Grosvenor Gardens, belonging to a private company which has been formed by a few Fellows for the purchase of the lease of this house. The proximity of the situation to Victoria Station makes it readily accessible from all parts of London, while the position, lying back from any main artery of traffic, will be free from the noise which forms an objectionable feature of the present premises. The first floor contains a large and lofty room which will be excellently adapted for the Meetings of the Society, while on the upper storeys good accommodation can be provided for the library. The total space available will allow of considerable expansion in the future without overcrowding. Certain structural alterations have to be carried out to render the premises fit for their future use, but it is hoped to have these completed so that the Society can be comfortably housed during the coming summer.

LECTURE COMMITTEE.—The Council have decided to revive the scheme for lectures to be delivered to schools, local societies, and similar institutions, which has been in abeyance since the death of Mr. W. Marriott. A Committee has been appointed to make the necessary arrangements. This Committee has prepared a circular giving details of the proposed scheme, which will be circulated early in the new year to institutions where lectures have been delivered in the past and others likely to be nterested. It is proposed to select lecturers from among the Fellows. A provisional list of subjects has been prepared with a view to suggesting the scope of the scheme.

LIBRARY.—180 volumes and 240 pamphlets and charts have been added to the Library during the year.

INSTRUMENTS.—The two sets of instruments which were lent to observers at Tenbury and Irvinestown in 1916 are still at these stations. The observations from Tenbury are published regularly in the *Monthly*

For Continuation of the Report of the Council, see page 194.

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APPENDIX

STATEMENT OF RECEIPTS AND EXPENDITURE

RECEIPTS.

Balance from 1918—Cash at Bank of England . . .	£116 7 9		
Do. Deposit at London County, Westminster, and Parr's Bank	300 0 0		
		£416	7 9
Subscriptions for 1919	£1095 7 11		
Do. for former years	75 4 2		
Do. for 1920	69 0 0		
Life Compositions	100 0 0		
Entrance Fees	96 0 0		
		1435	12 1
Dividends and Interest (including £78 : 2 : 2 from the New Premises Fund towards rent of Offices at 70 Victoria Street)		212	8 10
Sale of Publications, Advertisements, etc.		132	6 10
		£2196	15 6

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I.

FOR THE YEAR ENDING DECEMBER 31, 1919.

PAYMENTS.

Journal, etc.—					
Quarterly Journal, Nos. 189-192	£636	15	0		
Illustrations	44	1	0		
Reprints of Papers	55	7	0		
Reviews	5	16	6		
Monthly Weather Report, 15 parts and Annual Summary	46	5	7		
				£788	5 1
Printing, etc.—					
General Printing	£37	14	3		
Stationery	33	1	10		
Books and Bookbinding	15	3	3		
				85	19 4
Offices Expenses, etc.—					
Salaries	£499	11	5		
Do. Work on Climatological Atlas	50	0	0		
International Catalogue	25	0	0		
Postage	104	7	6		
Telephone Charges	7	9	0		
Auditing Accounts for 1918	6	6	0		
Petty Expenses	7	7	2		
Howard Medal	1	17	10		
Conjoint Board of Scientific Societies	10	0	0		
				711	18 11
Rent, etc.—					
Rent	£212	0	0		
Coals, Lighting, and Insurance	11	2	1		
Tenancy Agreement for 1920	4	10	0		
Furniture and Repairs	4	7	10		
				231	19 11
Meetings—					
Meeting Expenses, Refreshments, etc.	£15	1	9		
Lecture	10	10	0		
				25	11 9
Contributions—					
New Premises Fund	£100	0	0		
				100	0 0
Balances—					
Cash at Bank of England	£53	0	6		
Deposit at London County, Westminster, and Parr's Bank	200	0	0		
				253	0 6
				£2196	15 6

Examined, compared with vouchers, and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

1 Gresham Buildings, Basinghall St.,
London, E.C.2, *January* 12, 1920.

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APPENDIX

ASSETS AND LIABILITIES,

LIABILITIES.

Subscriptions paid in advance	£69 0 0		
Rent for quarter ending December 25, 1919	53 0 0		
Coals and Electric Light	3 3 9		
		£125	3 9
Excess of Assets over Liabilities[1]		2655	15 5
		£2780	19 2

[1] This excess is exclusive of the value of the Library and stock of Publications.

NEW PREMISES FUND,

RECEIPTS.

Contribution from Society's General Account	£100 0 0		
Dividends on Investments	78 2 2		
		£178	2 2
		£178	2 2

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I.—continued.

DECEMBER 31, 1919.

ASSETS.

Great Central Railway 4½ per cent Debenture Stock, £800 at 72½	£580	0	0			
New South Wales 4 per cent Inscribed Stock, 1933, £800 at 78½	628	0	0			
Victoria 3½ per cent Loan, 1921–26, £300 at 84½	253	10	0			
London & North-Western Railway Consolidated Stock, £400 at 96	384	0	0			
London & North-Western Railway 4 per cent Preference Stock, £112 at 68	76	3	2			
Annuities, 2½ per cent, £231 : 11 : 9 at 46¾	108	5	4			
War Stock, 5 per cent, 1929–1947, £105 : 5 : 3 at 91½	96	6	4			
				£2126	4	10

Note.—The above Stock are valued at prices estimated by the Society's Broker.

Subscriptions unpaid, estimated at	£50	0	0			
Entrance Fees unpaid	16	0	0			
Interest due on Stock	48	12	5			
				114	12	5
Furniture, Fittings, etc.	£222	2	7			
Instruments	64	18	10			
				287	1	5
Cash at Bank of England	£53	0	6			
Deposit at London County, Westminster, and Parr's Bank	200	0	0			
				253	0	6
				£2780	19	2

Examined, and Securities seen.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 12, 1920.

DECEMBER 31, 1919.

PAYMENTS.

£100 Registered 5 per cent National War Bonds, 1928	£100	0	0			
Paid to Society's General Account towards rent of Offices at 70 Victoria Street	78	2	2			
				£178	2	2
				£178	2	2

Note.—The Society holds on account of this Fund £1600 South Australian 3½ per cent Inscribed Stock, 1939; £217 : 11 : 2 New South Wales 3 per cent Loan, 1935; £150 5 per cent War Stock, 1929–1947; £100 5 per cent National War Bonds, 1927; and £100 Registered 5 per cent National War Bonds, 1928.

Examined and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 12, 1920.

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APPENDIX

RESEARCH FUND,

RECEIPTS.

Balance, January 1, 1919—Cash at Bank of England	£7 14 10
Dividends and Interest	8 5 6
	£16 0 4

SYMONS MEMORIAL FUND,

RECEIPTS.

Balance from 1918—Cash at Bank of England	£22 17 0	
Deposit at London County, Westminster, and Parr's Bank	40 0 0	
		£62 17 0
Interest received on Investment and Deposit		23 16 11
		£86 13 11

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I.—continued.

DECEMBER 31, 1919.

PAYMENTS.

Balance, December 31, 1919—Cash at Bank of England . . .	£16 0 4
	£16 0 4

Note.—The Society holds on account of this Fund £85:9:1 Consols, and £122:18:8 5 per cent War Stock, 1929–1947.

Examined and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 12, 1920.

DECEMBER 31, 1919.

PAYMENTS.

£50 Registered 5 per cent National War Bonds, 1928	£50 0 0
Balance—Cash at Bank of England	36 13 11
	£86 13 11

Note.—The Society holds on account of this Fund £700 Cardiff Corporation Redeemable Stock, 3 per cent, and £50 Registered 5 per cent National War Bonds, 1928.

Examined and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 12, 1920.

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Weather Report, but it has not yet been found possible to take regular readings at Irvinestown.

The binoculars which were lent in 1916 to the Lady Roberts' Field Glass Fund, National Service League, have now been returned to the Society.

PHENOLOGICAL REPORT. — Messrs. J. Edmund Clark and H. B. Adames presented the Phenological Report for the year 1918 at the Meeting held in May 1919, and it has been published in the October number of the *Quarterly Journal*.

CLIMATOLOGICAL ATLAS.—The preparation of the material for a Climatological Atlas of the British Isles, an enterprise which was undertaken in 1912, was interrupted by the War. The joint Committee representing the Society and the Meteorological Office was reconstructed in 1919 and progress has been made in the mapping of the data for the first volume of the Atlas. Mr. W. A. Bion, formerly of the Indian Meteorological Service, has been engaged in the work. Arrangements for the publication of the Atlas are now under consideration.

PUBLICATIONS.—*Quarterly Journal.* Despite the increase in the cost of printing, which has been very heavy, it has been found possible to continue the regular publication of the *Quarterly Journal* without diminution of size. On the contrary, the volume for 1919 exceeds any past volume in number of pages with the single exception of that for 1917.

The *Monthly Weather Report* of the Meteorological Office has been distributed to Fellows regularly throughout the year. The issue of this publication to Fellows abroad, restricted during the war, was resumed in May 1919.

MEETINGS.—Eight ordinary Meetings have been held during the year. The January and March Meetings were held in the rooms of the Geological Society, Burlington House. At the Meeting in March a lecture was delivered by Dr. Leonard Hill, F.R.S., on "Atmospheric Conditions which affect Health." On July 2 a special Summer Meeting of the Society was held at Kew Observatory, which was thrown open to Fellows of the Society through the kindness of the Director of the Meteorological Office and the Superintendent of the Observatory. On November 7 a special Meeting was held at the Society's rooms, at which Prof. V. Bjerknes of the Geophysical Institute, Bergen, delivered a lecture on "The Structure of the Atmosphere when Rain is falling." In this lecture some recent researches carried out at Prof. Bjerknes's instigation at the University of Bergen were summarized.

SYMONS MEDAL.—The Council have awarded the Symons Gold Medal to Prof. H. H. Hildebrandsson, of the University of Upsala, for his long-continued and distinguished work in Meteorology.

HOWARD MEDAL.—Upon the recommendation of Mr. C. E. P. Brooks, the Howard Medal has been awarded to Cadet E. L. Percival, of H.M.S. *Worcester*, for his essay on "The Meteorology of the Atlantic Ocean."

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APPENDIX II.

DONORS TO THE LIBRARY DURING THE YEAR 1919.

1. Institutions.

Aachen, Meteorologische Observatorium.
Athens, Observatoire National.

Bangalore, Mysore Government Meteorological Department.
Barbados, Colonial Secretary's Office.
Batavia, Royal Magnetical and Meteorological Observatory.
Bathurst, Gambia Government.
Beira, Observatorio Meteorologico.
Bello Horizonte, Minas Geraes, Brazil, Serviço de Meteorologia.
Berkeley, University of California.
Berwickshire Naturalists' Club.
Bombay and Alibag Observatory.
Brighton and Hove Natural History Society.
Brisbane, Royal Geographical Society.
Brussels, Académie Royale de Belgique.
Buenos Aires, Oficina Meteorológica Nacional.

Cairo, Egyptian Government.
Cairo, Physical Service.
California, Scripps Institution for Biological Research.
Cambridge, Mass., Harvard College Observatory.
Cambridge, Mass., Harvard University Press.
Cambridge, Solar Physics Observatory.
Cambridge, University Press.
Cape Town, Royal Society of South Africa.
Cape Town, South African Association for the Advancement of Science.
Caradoc and Severn Valley Field Club.
Cardiff, Naturalists' Society.
Christiania, Norsk Meteorologisk Institut.
Christ's Hospital, West Horsham, Natural History Society.
Cienfuegos, Cuba, Observatorio de Montserrat.
Coimbra, Observatorio Meteorologico.
Colombo, Observatory.
Copenhagen, Conseil Permanent pour l'Exploration de la Mer.
Copenhagen, Dansk Meteorologisk Institut.
Cordoba, Oficina Meteorológica Argentina.
Cornwall, Royal Polytechnic Society.
Croydon, Natural History and Scientific Society.

Davos, Kurverein.
Dorpat, Meteorologische Observatorium.
Dublin, General Register Office.
Dublin, Royal Dublin Society.
Dublin, Royal Irish Academy.

Ealing Scientific and Microscopical Society.
Edinburgh, Astronomer Royal for Scotland.
Edinburgh, General Register Office.
Edinburgh, Royal Scottish Geographical Society.
Edinburgh, Royal Society.
Edinburgh, Scottish Meteorological Society.
Elizabethville, Vice-Gouvernement Général du Katanga.

Geneva, Société de Géographie.
Genoa, R. Istituto Idrografico.
Georgetown, British Guiana, Dept. Science and Agriculture.
Greenwich, Royal Observatory.
Grenada, Colonial Secretary's Office.

Halifax, Nova Scotia Institute of Science.
Hankow, Boy Scouts Association of China.
Havana, Observatorio del Colegio de Belen.
Havana, Secretaria de Agricultura, Comercio y Trabajo, República de Cuba.
Helsingfors, Hydrografisk-Biologiska Hafsundersökningarna.
Hong-Kong, Royal Observatory.

Jamaica, Government Meteorologist.
Jinsen (Chemulpo), Korea, Meteorological Observatory.

Lisbon, Observatorio Infante D. Luiz.
Lisbon, Sociedad de Geographia.
Liverpool, Corporation Tramways.
Liverpool, Engineering Society.
Liverpool, Literary and Philosophical Society.
Logan, Utah, Agricultural College Experiment Station.
London, Admiralty, Hydrographic Department.
London, Air Ministry.
London, Board of Agriculture and Fisheries.
London, British Association for the Advancement of Science.
London, British Rainfall Organisation.
London, General Register Office.
London, Geological Society.
London, Geological Survey, England and Wales.
London, Institution of Electrical Engineers.
London, Institution of Sanitary Engineers.
London, Institution of Water Engineers.
London, Marconi Wireless Telegraph Company.
London, Meteorological Office.
London, Ministry of Munitions.
London, Physical Society.
London, Royal Aeronautical Society.
London, Royal Agricultural Society.
London, Royal Astronomical Society.
London, Royal Botanic Society.
London, Royal Geographical Society.

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London, Royal Sanitary Institute.
London, Royal Society.
London, Royal Society of Arts.
London, Royal Statistical Society.
London, Royaume de Belgique, Ministère des Colonies.
Lourenço Marques, Observatorio Campos Rodrigues.

Madrid, Instituto Geografico y Estadistico.
Madrid, Real Sociedad Geográfica.
Malta, Meteorological Observatory.
Manchester, Literary and Philosophical Society.
Manila, Weather Bureau.
Marlborough College Natural History Society.
Marseilles, Commission Météorologique du Département des Bouches-du-Rhône.
Mauritius, Royal Alfred Observatory.
Melbourne, Commonwealth Weather Bureau.
Melbourne, Department of Agriculture of Victoria.
Mesopotamia, Acting Civil Commissioner.
Mexico, Secretaria de Fomento.
Mexico, Sociedad Cientifica Antonio Alzate.
Milan, R. Osservatorio Astronomico di Brera.
Mizusawa, International Latitude Observatory.
Montevideo, Instituto Nacional de Agronomia.
Munich, Bayerische Landeswetterwarte.

New York, American Geographical Society.
New York, Central Park Observatory.

Oña, Spain, Colegio Maximo de la Compañia de Jesus.
Ôsaka, Meteorological Observatory.
Ottawa, Department of Mines.
Ottawa, Dominion Observatory.
Ottawa, Royal Society of Canada.
Oxford, Radcliffe Observatory.
Oxford University Press.

Pahang, F.M.S., Administration.
Panama, Isthmian Canal Commission.
Paris, Bureau Central Météorologique de France.
Paris, Service Météorologique aux Armées.
Paris, Société Météorologique de France.
Parma, Ufficio Idrografico del Po.
Perth, Western Australia, Government Statistician.
Perthshire Society of Natural Science.
Philadelphia, American Climatological and Clinical Association.
Philadelphia, American Philosophical Society.
Phu-Lien, Observatoire Central de l'Indochine.
Porto Alegre, Brazil, Instituto Astronomico e Meteorologico da Escola de Engenharia.
Punta Arenas, Observatorio Meteorológico Salesiano, Colegio San José.

Rio de Janeiro, Observatorio Nacional.
Rome, International Institute of Agriculture.
Rome, Reale Società Geografica Italiana.
Rome, Società Sismologica Italiana.
Rome, Ufficio Centrale Meteorologico e Geodinamico.

St. Croix, Virgin Islands, Agricultural Experiment Station.
St. Gallen, Ostschweizerische geographkommerzielle Gesellschaft.
St. Lucia, Government Office.
San Fernando, Instituto y Observatorio de Marina.
Sao Paulo, Secretaria da Agricultura, Comercio e Obras Publicas.
Shoeburyness, Superintendent of Experiments.
Simla, Meteorological Office.
Southport, Fernley Observatory.
Stockholm, Hydrografiska Byrån.
Stockholm, Institut Central de Météorologie.
Stonyhurst College Observatory.
Subiaco, Observatorio di Montecassino.
Sydney, Royal Society of New South Wales.

Tôhoku, Imperial University.
Tokio, Central Meteorological Observatory.
Tokio, Meteorological Society of Japan.
Toronto, Meteorological Office.
Toronto, Observatory.
Tortosa, Observatorio del Ebro.
Tsingtau, Meteorological Observatory.
Turin, Società Meteorologica Italiana.

Upsala, Observatoire Météorologique de l'Université.
Utrecht, K. Nederlandsch Meteorologisch Instituut.

Venezuela, Red Meteorologica.
Venice, Ufficio Idrografico.
Victoria, B.C. Government.
Vladivostok, Observatoire Météorologique.

Washington, Carnegie Institution.
Washington, Coast and Geodetic Survey.
Washington, Forest Investigation Committee.
Washington, Hydrographic Office.
Washington, National Academy of Sciences.
Washington, Office of the Panama Canal.
Washington, Smithsonian Institution.
Washington, U.S. Department of Agriculture.
Washington, Weather Bureau.
Wellington, N.Z., Government Statistician.
Wellington, N.Z., Meteorological Office.
Wisconsin, Academy of Sciences, Arts and Letters.

Yale, University Press.
Yokohama, Asiatic Society of Japan.
Yorkshire Philosophical Society.

Zi-Ka-Wei, Observatoire Magnétique, Météorologique et Sismologique.
Zomba, Meteorological Department.
Zürich, Schweizerische Meteorologische Central-Anstalt.

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2. INDIVIDUALS.

Dr. T. Agius.
K. Aichi.
P. G. Alfani.
Dr. A. Angot.
E. C. Barton.
J. Baxendell.
F. Campbell Bayard.
F. H. Bigelow.
L. C. W. Bonacina.
Rev. H. A. Boys.
C. F. Brooks.
A. Brown & Dr. P. Boobbyer.
J. Y. Buchanan.
Dr. C. Chree.
A. Collenette.
Rev. M. Dechevrens.
C. Dixon.
J. Dover.
H. N. Edge.
N. Ekholm.
Prof. F. Eredia.
Dr. E. Fontseré.
W. L. Fox.
Messrs. Gauthier-Villars et Cie.
R. Gautier et E. Rod.
Dr. G. Hinsdale.
U. Hoepli.
N. Holden.
D. W. Horner.
R. E. Horton.
H. Hubert.
A. F. Hunter.
J. Hunter.
Dr. H. Jeffreys.
E. Lamb.
G. C. Lawson.
F. Lindholm.
Miss G. Loft.
F. Lowe.
J. McEwan.
Messrs. Macmillan & Co.
Maj. C. A. Markham.
Miss C. Marshall.
H. Mellish.
A. Meyer.
T. Midgley.
H. Milford.
Dr. H. R. Mill.
Sir J. W. Moore.
R. C. Mossman.
E. W. M. Murphy.
W. C. Nash.
Capt. G. Ota.
J. M. Parnaby.
B. V. Pemberton.
Messrs. G. Philip & Son, Ltd.
W. H. Pickering.
A. W. Preston.
F. F. Roget.
C. Salter.
Dr. O. M. Skord.
R. B. Sleight.
Dr. E. H. Snell.
Dr. T. E. Stanton.
C. Stewart.
Dr. G. Taylor.
L. G. Tippenhauer.
L. Ugueto.
Dr. J. F. Unstead.
Dr. A. E. Waller.
Prof. R. De C. Ward.
Sir W. Willcocks and J. Wells.
A. J. Wilmshurst.
Messrs. Witherby & Co.

The Editors of—

Athenaeum.
Flying.
Indian Engineering.
La Conquête de l'Air.
Nature.
Observatory.
Revue du Ciel.

SYMONS MEMORIAL MEDAL, 1920.

(Plate 1.)

The presentation of the Symons Memorial Medal for 1920 was made at the Annual General Meeting of the Society on January 21, the recipient being Prof. HILDEBRAND H. HILDEBRANDSSON of Upsala. The medal was presented to His Excellency the Swedish Minister, Count H. Wrangel, who received it on behalf of Professor Hildebrandsson.

The SECRETARY read the following extract from the Minutes of the Council Meeting of November 19, 1919 :—

"Professor Hildebrand H. Hildebrandsson was born at Stockholm in 1838 and was educated at the University of Upsala, with which he has maintained his connection throughout his life. He took the degree of Doctor of Philosophy in 1866. In 1878 he became the first Professor of Meteorology of the University and Director of its Meteorological Observatory, a position which he continued to hold until his retirement in 1906. Throughout his career he has taken a prominent part in the organisation of international meteorological enterprises. He is one of the few delegates who attended the first International Congress at Leipzig in 1869 who are still with us, and was a regular attendant at subsequent international meetings. He was a member of the International Meteorological Committee and served as its Secretary from 1903 until 1906.

"He has been an Honorary Fellow of our Society since 1880.

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"His scientific work in Meteorology has covered a wide field. As in the case of other Scandinavian meteorologists his attention was directed by force of circumstances to polar research, in which connection he discussed the observations made during the voyage of the *Vega* from the North Cape to Yokohama through Bering Strait. Among his earlier works mention must also be made of his papers on the distribution of meteorological elements with reference to centres of maximum and minimum pressure, which appeared in 1883.

"Hildebrandsson did much to advance the study of cloud. In conjunction with the late Teisserenc de Bort he was requested by the International Meteorological Committee to prepare the *International Cloud Atlas*. He took a prominent part in organising the international cloud observations made during the year 1896–7 and at the request of the International Committee undertook the task of summarising and discussing the results. His reports on this subject form most important contributions to our knowledge of the general circulation of the atmosphere and gave for the first time a working hypothesis of the general circulation based on observed fact as opposed to speculation. They have been incorporated in the monumental work *Les bases de la météorologie dynamique* which he prepared in collaboration with Teisserenc de Bort.

"In late years Hildebrandsson turned his attention to the study of what he has termed 'centres of action' of the atmosphere, another aspect of the problem of world meteorology. His many papers on this subject constitute an important advance in the difficult question of seasonal forecasts."

The PRESIDENT then said: Your Excellency, while endorsing all that is said in the official Minute which you have heard read, and which fully justified the award of the Symons Medal, I should like to supplement it by things drawn from my own personal experience. My official association with Hildebrandsson began 20 years ago at the top of the Eiffel Tower in Paris and has been continued at International Meetings at Southport, Paris and Petrograd. I am sorry to say not in London. I have never seen Hildebrandsson in London, and the hope of seeing him here is now getting rather dim for he is in his 82nd year. But in spite of his great age he retains unexampled activity. During those 20 years I know from personal experience that Hildebrandsson has kept in view the definite meteorological ideal that before making any meteorological theory of an elaborate character it was necessary to have the meteorological facts, and for those facts to be put together in the form of an ordered whole from which generalisations can be drawn. In that feeling he differed from many preceding meteorologists, but he shared it with his colleague Teisserenc de Bort. Those who care to look at that wonderful book *Les bases de la météorologie dynamique* will be able to trace the steps along which they intended to lead meteorology to the realisation of its great purposes. When I take down that book I always wonder who paid for it. It is an astonishing book full of illustrations of original documents, reproduced according to size and colour as they originally appeared. In meteorological study there is no substitute for original documents except reproduction in facsimile, and the debt of gratitude we owe for so magnificent a publication is considerable. It

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PROFESSOR HILDEBRAND H. HILDEBRANDSSON.

(*Symons Medallist*, 1920.)

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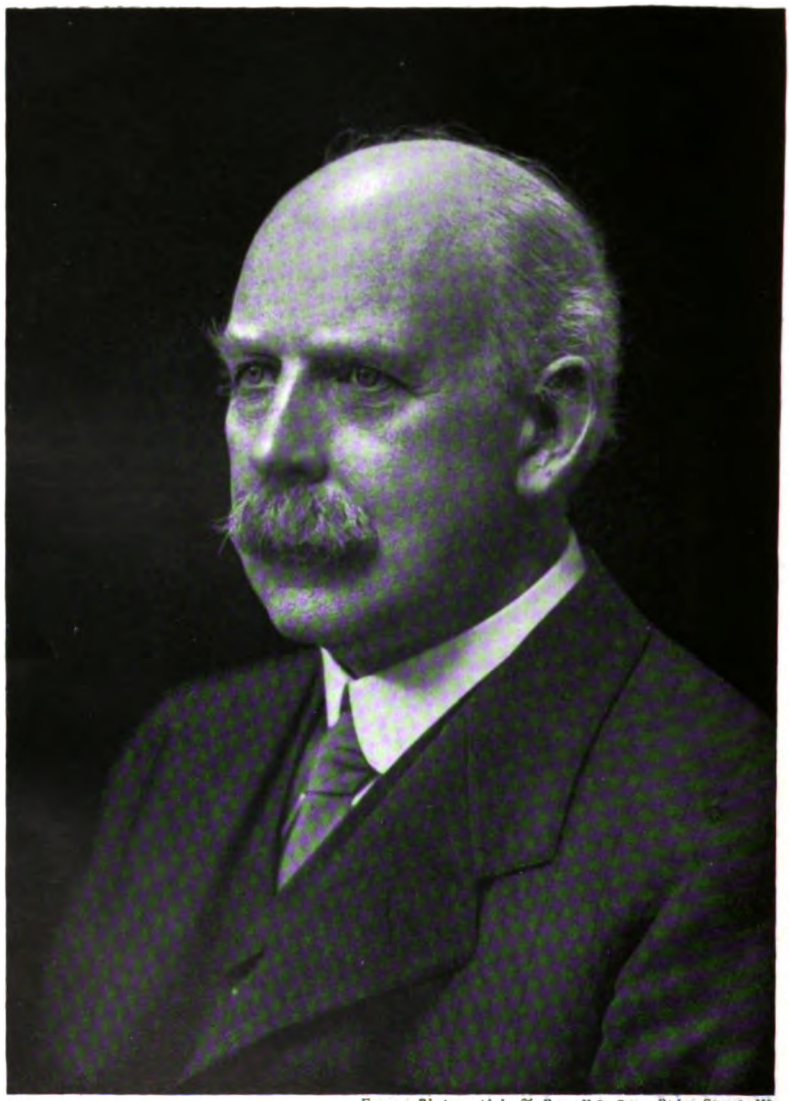

From a Photograph by J. Russell & Sons, Baker Street, W.

SIR NAPIER SHAW, F.R.S.

(*President of the* ***Royal Meteorological Society***, 1918–1919.)

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was Hildebrandsson who shared the inspiration and his enthusiasm for meteorological facts, and the ordering of them into a feasible and workable character was evident in his great efforts for the *Réseau Mondial* and in his recent contribution on "The General Circulation of the Atmosphere" which we have all read with great pleasure. And finally as a colleague. I do not know that there ever was a more friendly, more sociable and more kindly body than the old Meteorological Committee. We never met to quarrel but to help one another in the most effective manner. Hildebrandsson was the Secretary from 1903 up to the formulation of regulations for the International Committee in 1907. We have now to begin again with another Secretary, but I can assure Your Excellency that the courtly, genial presence of Hildebrandsson at the international assembly will always be gratefully remembered by his colleagues. You will allow me to present to you the Symons Medal and to assure you that it carries with it our wishes for long life and continued activity in the science, our sympathy with Hildebrandsson in the work that he has embellished and our desire to further that work in the future.

His Excellency COUNT H. WRANGEL said: I beg to accept on Prof. Hildebrandsson's behalf this most agreeable honour which you have conferred on him in giving him this beautiful Medal and I know that his regret that he could not be present to receive it is very great indeed. I shall give him a full report of all that has been said, and I know that he will be very much touched by the many kind things that have been said about his work.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

January 21, 1920.

Ordinary Meeting.

Sir NAPIER SHAW, F.R.S., President, in the Chair.

HAROLD WILBY BAKER, Church Street, Watlington, Oxon.;
WILLIAM REGINALD BALLINGER, 16 Conduit Street, Gloucester;
Lieut. FRANK OWEN BASSETT, 18 Elsie Road, East Dulwich, S.E.22;
Captain JOHN HAROLD BASSETT, 16 Polwarth Gardens, Hyndland, Glasgow;
JAMES ESMOND BELASCO, B.Sc., 39 Bramerton Street, Chelsea, S.W.3;
LEWEN HENRY GEORGE DINES, M.A., Assoc.M.Inst.C.E., Valencia Observatory, Cahirciveen, Co. Kerry;
ODD HENRICHSEN, 5 Clarkson Street, Sheffield;
JEREMIAH LEAHY, 11 Sully Terrace, Penarth, Cardiff;
GEORGE FLETCHER MORTON, M.A., Lyley House, Wotton-u.-Edge, Glos.; and
JAMES SNAILHAM SAMSON, 21 Well Close Mt., Blackman Lane, Leeds,

were balloted for and elected Fellows of the Society.

January 21, 1920.

Annual General Meeting.

Sir NAPIER SHAW, F.R.S., President, in the Chair.

Lieut. A. W. MACKAY and Lieut. S. C. RUSSELL were appointed scrutineers of the ballot for the Council.

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The Report of the Council which had been circulated to the Fellows of the Society at the Meeting, having been taken as read, its adoption was proposed by the President and seconded by the Secretary. The Meeting resolved "That the Report of the Council be received and adopted, and that it be printed in the *Quarterly Journal*" (p. 186).

The Minutes of the Council respecting the award of the Symons Gold Medal to Professor H. H. HILDEBRANDSSON of Upsala, for his distinguished work in connection with meteorological science, having been read by the Secretary, the President presented the Medal to H.E. Count H. Wrangel, the Swedish Minister, who was present to receive the Medal for transmission to Professor Hildebrandsson. Count Wrangel said a few words of thanks on behalf of Professor Hildebrandsson (p. 199).

The following By-Law was proposed by the PRESIDENT and seconded by Captain C. J. P. CAVE, and on being put to the Meeting was adopted:

BY-LAW 63A.—"Whereas, since the date of the establishment of the Society and of its incorporation by Royal Charter no payment of any dividend, gift, division or bonus in money has been made unto or between any member of the Society, and whereas the Society has hitherto been supported by donations and annual and other subscriptions and contributions and the income from investments arising therefrom, now it is hereby declared and enacted that the Society shall be supported wholly or in part by annual voluntary contributions and shall not make any dividend, gift, division or bonus in money unto or between any of its members."

Captain D. WILSON-BARKER in moving "That the thanks of the Society be given to the Council for their services during the past year" said that he knew very well how arduous was the work of the Council and how much time had to be given up to its Meetings. The President had been appointed Meteorological Adviser to the Government during his term of office and he felt that that reflected honour on the Society.

Dr. C. CHREE seconded the resolution and said that as well as thanking the President and Council for what they had done they should also thank them for what they had not done. They had not asked the Society to hold a Meeting to discuss the effect of Einstein's results on meteorology. The resolution was passed unanimously.

It was proposed by Mr. R. H. HOOKER, seconded by Mr. C. SALTER and resolved, "That the thanks of the Royal Meteorological Society be communicated to the President and Council of the Royal Astronomical Society for having granted the Society permission to hold its Annual General Meeting in the rooms of the Royal Astronomical Society."

The President then delivered an Address on "Pioneers in the Science of Weather" (p. 141).

Captain C. J. P. CAVE said they had all listened with the greatest interest to the President's Address and to the varied careers of the meteorologists who had gone before them and he wished to propose "That the thanks of the Society be given to Sir Napier Shaw for his services as President during the past year and for his Address, and that he be asked that the Address might be printed in the *Quarterly Journal*."

Mr. R. G. K. LEMPFERT said he had much pleasure in seconding the motion. As Captain Cave had referred more especially to the President's Address he would draw attention to the services that Sir Napier had given to the Society. He knew better than any one how arduous these services had been for one in Sir Napier's position and he thought the Society owed him a great deal for taking the Presidency and for all he had done.

The President (Sir NAPIER SHAW) said he thought he need not trouble them with words of thanks. So far as he was concerned the year had been a severe

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one and he had carried on with the thought that the immediate stress would soon be over, and he hoped the Society would find its future prosperity and activity were provided for as well as they could be in these difficult times.

The SCRUTINEERS then declared the following to be the Council for the ensuing year :—

PRESIDENT.

REGINALD HAWTHORN HOOKER, M.A., F.S.S.

VICE-PRESIDENTS.

JOSEPH BAXENDELL.
FRANCIS DRUCE, M.A., F.L.S., F.R.G.S.
Sir NAPIER SHAW, Sc.D., LL.D., F.R.S.
FRANCIS JOHN WELSH WHIPPLE, M.A.

TREASURER.

WILLIAM VAUX GRAHAM, M.Inst.C.E.

SECRETARIES.

WALTER WILLIAM BRYANT, B.A., F.R.A.S.
JOHN SOMERS DINES, M.A.

FOREIGN SECRETARY.

RUDOLF GUSTAV KARL LEMPFERT, M.A., C.B.E.

COUNCILLORS.

CHARLES ERNEST PELHAM BROOKS, M.Sc.
JOHN BROWNLEE, M.D., D.Sc.
Captain CHARLES JOHN PHILIP CAVE, M.A.
JAMES EDMUND CLARK, B.A., B.Sc., F.G.S.
RICHARD CORLESS, M.A., O.B.E.
GORDON MILLER BOURNE DOBSON, M.A.
JAMES FAIRGRIEVE, M.A., F.R.G.S.
Lieut. HUGH DUNCAN GRANT.
HENRY MELLISH, C.B., D.L., J.P., F.R.G.S.
JOSEPH ERNEST PETAVEL, D.Sc., F.R.S.
MORTYN DE CARLE SOWERBY SALTER.
GEOFFERY INGRAM TAYLOR, M.A., F.R.S.

Sir NAPIER SHAW in vacating the Chair in favour of Mr. R. H. HOOKER said it was his duty and pleasure to hand over the responsibilities of the Chair to Mr. R. H. Hooker of the Ministry of Agriculture and Fisheries. Mr. Hooker came of a very well-known family connected particularly with the science of Botany, and the association of Botany and Meteorology was so intimate that its expression by having an agriculturist as President of the Society was very fitly represented by the election of Mr. Hooker. Moreover Mr. Hooker knew the inside of a meteorological office as he had worked at the Meteorological Office. They would all remember Mr. Hooker's notable contribution to the application of meteorology to the growth of crops and would look forward to the development of that as well as of other subjects during the course of his Presidency. Sir Napier then gave the keys of office to Mr. Hooker, inviting him to take the Chair, with his best wishes and the congratulations of the Fellows and their desire to support him in every way.

Mr. R. H. HOOKER thanked the Fellows for the very great honour they had

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done him in electing him President, and Sir Napier Shaw for the kind words in which he had welcomed him. No one was more conscious than himself of his lack of qualifications which the very brilliant succession of Presidents, chief amongst whom was Sir Napier himself, only served to enhance. He recognised that he would have to make up for his disqualifications by hard work and in this he would have to rely very largely on the help of the Council and especially the Honorary Secretaries. He accepted the keys of office as a symbol binding him to the service of the Society.

February 18, 1920.

Ordinary Meeting.

Mr. R. H. HOOKER, M.A., President, in the Chair.

ROWLAND ARNISON, Fan-Foel, Oakhill Gardens, Woodford Green, Essex;

CHARLES FRANKLIN BROOKS, Ph.D., 3903 Ingomar Street, Chevy Chase, Washington, D.C., U.S.A.;

SYDNEY CHAPMAN, M.A., D.Sc., F.R.S., Professor of Mathematics and Natural Philosophy, University of Manchester;

Brevet-Major FREDERICK WILLIAM DARWALL, 6 East Cliff, Dover;

HAROLD PERCY POWELL FLEWITT, B.Sc., 57 Pendennis Street, Anfield, Liverpool;

Major ANGUS GRAHAM MACDONALD, O.B.E., M.D., D.P.H., D.I.M., 57 Room, Cornwall House, Stamford Street, S.E.1;

WILLIAM NICHOLS, 7 Charlbury Buildings, Hunstanton, Norfolk;

Captain AUSTIN HENRY DE COURCEY QUINCE, White House, Nailsea, Somerset;

ERNEST MACLAGAN WEDDERBURN, O.B.E., D.Sc., F.R.S.E., 6 Succoth Gardens, Edinburgh; and

ROBERT STEWART WHIPPLE, M.I.E.E., 15 Creighton Avenue, Muswell Hill, N.10,

were balloted for and elected Fellows of the Society.

The following communications were read:—

1. "THE STATUS OF A METEOROLOGICAL OFFICE AND ITS RELATION TO THE STATE AND THE PUBLIC." By Captain C. J. P. CAVE, F.R.Met.Soc. (p. 155).

2. "ATMOSPHERIC AND TERRESTRIAL RADIATION." By W. H. DINES, F.R.S., F.R.Met.Soc. (p. 163).

3. "INTERNAL FRICTION IN THE ATMOSPHERE." By DAVID BRUNT, M.A., B.Sc., F.R.Met.Soc. (p. 175).

CORRESPONDENCE AND NOTES.

Exceptional Rainfall on Hawaiian Mountain Peaks.

In a brief article in the *Monthly Weather Review* for May 1919 Mr. G. K. Larrison gives some interesting details respecting the rainfall recorded on some of the highest peaks of the Hawaiian Islands. In the course of their high-level hydrometric work the engineers of the U.S. Geological Survey found it necessary to measure the rainfall at a number of points up to more than 5000 feet above sea-level. Unfortunately, owing to the inaccessibility of many of the

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higher peaks of the mountains, it was found impossible to maintain observations covering the whole of the period of the survey, but sufficient data have been acquired to cause the author to challenge the reputation of Cherrapunji in the Khasi Hills of India as having the largest annual rainfall in the world. During the periods August 2, 1911, to March 26, 1914, and May 31, 1915, to August 13, 1917, a total of 1782 days, there was recorded on Mount Waialeale in the Island of Kauai, at an elevation of 5080 feet, a total precipitation of 2325 inches, or an average of 1·30 ins. per day. This the author computes would amount to a precipitation of about 476 inches in a 365-day year, as against 426 inches as recorded at Cherrapunji. Complete records were not obtained from this station during 1914 or 1918, but the local Weather Bureau Office figures show that these years were both extremely wet, and it is assumed by comparison that the annual rainfall for 1914 and 1918 at Mount Waialeale would have exceeded 600 inches. For the period May 21, 1915, to May 30, 1916, the recorded rainfall at this station was 561 inches.

There are several other wet spots in the Sandwich Islands. Puu Kukui, 5000 feet above sea-level, on the island of Maui, has an average precipitation of 369 inches, based on 7 years' observations, the maximun being 562 inches in 1918. On the island of Hawaii, at an elevation of 4000 feet, a rainfall of 504 inches was recorded in 1914, and at several other places all more than 1000 feet above sea-level, the rainfall in 1914 and 1918 exceeded 350 inches. The heaviest daily downpour recorded was 31·95 inches at Honomu, Hawaii (1200 feet), on February 20, 1918, the total rainfall for the year at this station being 379 inches.

A remarkable characteristic of the topography of the Hawaiian group of Islands is the high central mountain ridge with narrow precipitous valleys, flattening out as a rule to narrow plains along the sea coast. This peculiar geographical feature is reflected in the extraordinary variation in precipitation which occurs, and the author claims that although Hawaii may have to be satisfied with second place as to the annual quantities of rainfall, it challenges the world for variation in precipitation with vertical or horizontal distance.

These are shown in the following table:—

Station.	Height.	Distance from Waialeale.	Rainfall.
KAUAI—	feet.	miles.	ins.
Mount Waialeale .	5080	...	476
Olokele . . .	2100	2·0 SW	149
Kokee . . .	3550	10·5 NW	56
Pali Trail . . .	850	11·0 SW	16
North Wailua . .	650	4·0 E	126

Similar wide variations are to be found in the records from the various stations in the other islands of the group, the smallest precipitation in every case being found to the westward of the highest peaks. This is no doubt accounted for by the prevailing wind blowing from a north-easterly direction and the warm vapour-charged winds from the sea depositing their moisture as they are carried up the mountain slopes, descending on the further side of the ridges in a comparatively dry state.

It should be mentioned that the greater part of the rainfall at Cherrapunji falls during the rainy season from April to September. In the high-level regions of the Hawaiian Islands there is no definite wet season, although the author of the article suggests that November to April are as a rule the wettest months.

A. H. B.

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The Distribution of Temperature over Nigeria.

In a former article[1] I have studied the distribution of rainfall over Nigeria. It was always intended to deal with the other elements in due course, but time has slipped away, and it is only after four years' interval that the study is resumed. The present paper deals briefly with the mean monthly temperature distribution.

Nigeria forms a four-sided area extending from the Gulf of Guinea in 4° N. to the latitude of Lake Tchad (14° N.), and lying between 2° and 14° E. long. From Lake Tchad, and the valleys of the rivers which flow into it from the west and south, the ground rises to a high plateau, the general level of which is above 1600 feet, while its highest point, Mount Zaranda, west of Bauchi, reaches about 6900 feet. This feature is known as the Bauchi Plateau. It is bounded on the west by the deep valley of the Niger, and on the south by its principal tributary, the Benue; southwards these open out into the damp lowland of the Niger delta and coastal plain.

The account of the temperature distribution here presented is in outline only. The periods are mostly short, the heights of the stations are not always known, and the figures for the Southern Province are not always reliable. The data for the stations in the Northern Province have been extracted from manuscript reports sent to the Meteorological Office by the Senior Medical Officer; those for the Southern Province are taken from the *Government Gazette*. Table I. gives for all stations employed the mean daily maximum (top line), the mean daily minimum (middle line) and the mean of these two (bottom line). The co-ordinates, height and period covered are also specified.

These figures refer to the actual observations, but the maps refer to mean sea-level. The method of reduction was as follows: The mean annual temperatures were first reduced to mean sea-level for all stations whose heights were known, the corrections being additive at the rate of 3° F. per 1000 feet. These figures were plotted, and a set of isotherms was drawn from them. These isotherms were then used to obtain corrections for the other stations whose heights were not known; the corrections so obtained were employed to reduce the monthly means. No attempt has been made to reduce the series to a uniform period.

The positions of the stations are shown in Fig. 1. These are seen to cluster thickly in the south, but to be more scattered in the north; fortunately the latter appear to give very reliable data which reflect great credit on the observers, generally Medical Officers. Fig. 1 also gives the mean annual isotherms reduced to sea-level. These show that the highest temperatures, above 85° F., are found on the southern slopes of the Bauchi Plateau, extending across the Benue River, and on the north bank of the Niger near Jebba, and again in the extreme north of the Colony. The lowest temperatures, just below 80°, are met with near the coast to the west of the Niger, extending across the delta.

The continuous lines in Fig. 2 show the mean daily range, that is, the difference between the mean daily maximum and mean daily minimum for the year. This range is seen to increase from below 15° F. on the coast (Lagos 10°·6 F.) to above 30° F. near Lake Tchad. The increase is associated with a decrease of the rainfall, humidity and cloudiness as the coast is left behind, and the desert conditions of the Sahara are approached, and it more than counterbalances the rise of mean temperature northward, so that the lowest mean minima are found in the north-east.

The shaded areas separated by broken lines are those in which the highest mean temperature is reached in different months. February is the warmest

[1] *London, Q. J. R. Meteor. Soc.*, **42**, 1916, p. 85.

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month at the mouth of the Niger, and in part of the eastern half of the Southern Provinces; March is warmest over most of the Southern Provinces,

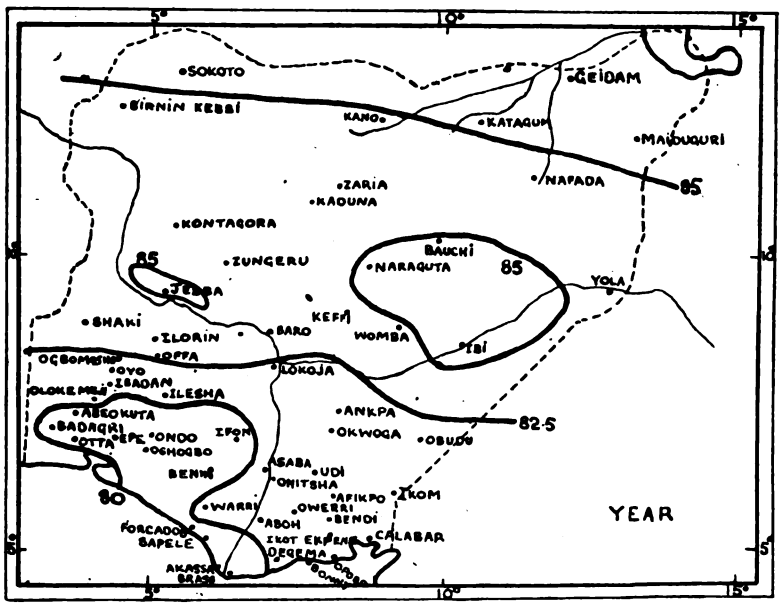

FIG. 1.—Mean Annual Isotherms (reduced to Mean Sea-Level); Positions of Stations.

April over the greater part of the Northern Provinces, and May in the extreme north. Comparison with the rainfall charts shows that in each case it is the last month of the dry season that is the warmest; the cloud and rain of

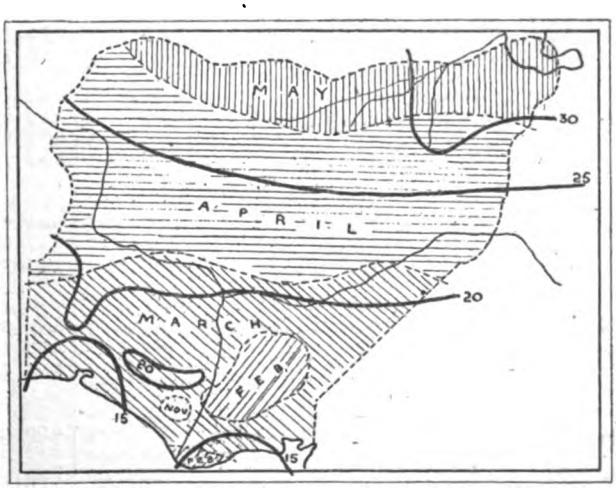

FIG. 2.—Months with Highest Mean Temperature (shaded) and Lines of Equal Daily Range.

the wet period bring about a fall of temperature. At one station, Warri, November has the highest temperature.

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TABLE I.—Temperatures in Nigeria.

Note.—At each station the top line is the mean daily maximum, middle line the mean daily minimum, bottom line the mean of these two.

Stations, Positions, and Periods of Observation.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Sokoto	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
13°02′ N 5°14′ E	87·8	92·7	100·0	104·0	102·0	96·1	89·6	86·3	89·9	95·2	94·4	87·8	93·8
1160 ft. . .	60·9	64·8	71·1	77·5	79·5	76·6	73·4	72·1	72·8	71·8	66·2	61·4	70·7
1907–1915 .	74·3	78·7	85·5	90·7	90·7	86·3	81·5	79·2	81·3	83·5	80·3	74·6	82·2
Birnin Kebbi													
12 28 N 4 11 E	90·0	95·5	101·5	104·0	100·9	95·4	90·9	87·9	90·8	95·1	94·7	89·2	94·7
900 ft. . .	57·9	62·3	68·4	76·6	76·9	74·7	72·1	71·3	71·6	70·8	63·3	57·7	68·6
1909–1915 .	73·9	78·9	84·9	90·3	88·9	85·1	81·5	79·6	81·2	82·9	79·0	73·4	81·6
Kano													
12 00 N 8 32 E	85·4	89·4	97·6	103·1	101·6	95·3	89·4	86·5	90·5	95·1	92·8	86·0	92·7
1510 ft. . .	54·4	57·7	64·1	73·2	75·1	72·9	70·6	69·4	70·7	67·0	58·4	53·9	65·6
1907–1915 .	69·9	73·5	80·9	88·1	88·3	84·1	80·0	77·9	80·6	81·1	75·6	69·9	79·2
Katagum													
12 17 N 10 22 E	88·6	94·2	101·6	106·3	104·3	99·4	91·5	87·9	91·7	96·6	93·2	87·2	95·2
1320 ft. . .	55·4	57·8	64·5	73·1	75·9	74·8	72·6	71·4	72·3	68·2	59·9	59·3	67·1
1907–1914 .	72·0	76·0	83·1	89·7	90·1	87·1	82·1	79·7	82·0	82·4	76·5	73·3	81·1
Geidam													
12 53 N 11 57 E	90·9	94·2	100·9	108·2	107·9	104·8	98·6	92·1	97·7	102·7	96·9	90·2	98·8
900 ft. . .	54·6	58·1	64·8	72·5	75·2	75·8	74·7	72·0	72·1	69·1	61·7	55·7	67·2
1909–1914 .	72·7	76·1	82·9	90·3	91·5	90·3	86·7	82·1	84·9	85·9	79·3	72·9	83·0
Zaria													
11 06 N 7 30 E	88·3	93·7	97·7	97·5	93·7	89·4	85·1	83·7	86·7	91·5	92·5	86·8	90·5
2230 ft. . .	56·5	59·4	65·2	71·2	70·3	68·8	68·1	67·5	67·1	64·8	57·4	54·9	64·3
1907, 1909–1915	72·4	76·5	81·5	84·3	82·0	79·1	76·6	75·6	76·9	78·1	74·9	70·9	77·4
Nafada													
11 06 N 11 17 E	91·7	96·0	101·0	105·1	102·5	97·8	92·3	88·7	90·6	96·2	96·5	91·3	95·8
950 ft. . .	51·7	58·8	64·3	72·8	74·9	73·3	72·0	70·5	70·0	65·0	55·0	52·9	65·1
1909–1914 .	71·7	77·4	82·7	88·9	88·7	80·5	82·1	79·6	80·3	80·6	75·7	72·1	80·5
Maiduguri													
11 47 N 13 11 E	92·0	95·9	103·6	108·1	107·3	101·5	94·0	89·3	92·5	98·9	97·3	90·7	97·6
1186 ft. . .	55·7	59·9	65·6	75·2	76·0	74·4	72·8	71·4	72·3	69·5	61·7	56·4	67·6
1906–1916 .	73·9	77·9	84·6	91·7	91·7	87·9	83·4	80·3	82·4	84·2	79·5	73·5	82·6
Kontagora													
10 24 N 5 24 E	94·4	97·7	99·9	98·2	94·1	88·9	85·4	84·1	86·1	90·2	94·5	93·9	92·3
1300 ft. . .	62·8	66·6	71·1	75·1	74·4	71·8	70·3	70·0	69·1	68·7	60·3	59·8	68·3
1906–1913 .	78·6	82·1	85·5	86·7	84·3	80·3	77·8	77·1	77·6	79·5	77·4	76·9	80·3
Kaduna													
10 50 N 7 25 E	90·1	92·4	95·0	95·0	90·1	85·9	83·4	82·4	84·5	89·0	90·9	87·9	88·9
2100 ft. . .	55·9	59·5	63·3	70·4	70·2	68·2	67·4	67·0	66·7	65·8	58·3	53·5	63·9
1913–1915 .	73·0	75·9	79·1	82·7	80·1	77·1	75·4	74·7	75·6	77·4	74·6	70·7	76·4
Bauchi													
10 19 N 9 49 E	88·7	91·7	96·4	98·7	95·8	91·0	86·7	84·4	86·5	91·0	92·1	87·8	90·9
2260 ft. . .	62·6	64·2	68·7	73·5	72·3	69·2	67·2	68·0	68·4	69·0	64·6	61·4	67·4
1909–1914 .	75·7	77·9	82·5	86·1	84·1	80·1	76·9	76·2	77·5	80·0	78·3	74·6	79·2
Jebba													
8 30 N 4 35 E.	95·0	98·8	101·8	101·0	93·7	89·4	85·7	86·9	87·2	91·2	94·5	93·6	93·2
1080 ft. . .	71·6	76·7	77·3	78·5	75·7	73·2	72·6	72·2	72·1	72·8	71·7	69·1	73·6
1913–1915 .	83·3	87·7	89·5	89·7	84·7	81·3	79·1	79·5	79·7	82·0	83·1	81·3	83·4

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TABLE I. (*continued*).—TEMPERATURES IN NIGERIA.

Stations, Positions, and Periods of Observation.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
ZUNGERU	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
9°49′ N 6°10′ E	94·6	98·2	100·0	98·1	93·6	89·3	86·2	85·3	86·9	90·4	94·4	94·1	92·6
608 ft. . .	65·6	68·8	73·7	76·4	74·4	71·9	71·3	71·0	70·3	70·4	64·5	63·9	70·2
1905–1915 .	80·1	83·5	86·9	87·3	84·0	80·6	78·7	78·1	78·6	80·4	79·5	79·0	81·4
NARAGUTA													
9 56 N 8 33 E.	84·8	88·2	90·8	89·6	87·3	83·8	80·3	78·1	82·3	85·1	86·3	82·3	84·9
4000 ft. . .	57·1	59·9	63·8	66·4	65·3	63·3	62·3	61·9	62·1	61·5	58·0	56·7	61·5
1911–1915 .	70·9	74·1	77·3	78·0	76·3	73·5	71·3	70·0	72·2	73·3	72·1	69·5	73·2
YOLA													
9 12 N 12 30 E	92·4	96·1	100·9	100·2	94·9	89·8	85·6	85·6	86·8	91·4	95·7	93·1	92·7
850 ft. . .	67·3	71·2	75·9	78·0	75·3	72·6	71·7	71·1	70·8	71·7	68·3	65·9	71·7
1904–1915 .	79·9	83·7	88·4	89·1	85·1	81·2	78·7	78·3	78·8	81·5	82·0	79·5	82·2
SHAKI													
8 41 N 3 24 E.	90·4	94·9	90·3	92·3	85·6	85·4	81·7	81·2	81·6	83·2	88·4	88·6	87·0
	67·7	65·6	67·3	66·7	69·5	69·7	68·9	70·1	69·0	67·0	68·3	68·8	68·2
1906–1909 .	79·1	80·3	78·8	79·5	77·5	77·5	75·3	75·7	75·3	75·1	76·3	78·7	77·6
OGBOMOSHO													
8 08 N 4 14 E.	94·5	97·0	97·3	91·9	89·0	85·4	83·2	82·1	83·4	87·1	90·8	93·0	89·6
1180 ft. . .	66·7	70·0	70·6	69·8	69·0	67·7	67·4	66·0	68·6	68·2	68·1	63·2	67·9
1907–09, 12–15 .	80·6	83·5	83·9	80·9	79·0	76·5	75·3	74·1	76·0	77·7	79·5	78·1	78·8
ILORIN													
8 30 N 4 35 E.	92·9	96·0	97·4	94·1	91·8	87·8	84·4	85·0	85·8	89·2	92·3	92·9	90·8
1080 ft. . .	64·4	69·6	70·9	71·7	70·4	69·0	68·0	68·1	68·9	69·3	67·8	61·6	68·3
1907–1915 .	78·7	82·8	84·1	82·9	81·1	78·4	76·2	76·5	77·3	79·3	80·1	77·3	79·6
BARO													
8 35 N 6 27 E.	96·5	100·9	102·9	100·5	96·3	92·5	89·7	89·5	90·8	94·3	97·4	95·8	95·6
	70·5	74·1	76·9	76·5	75·1	73·7	73·2	72·9	72·1	73·0	72·4	68·7	73·3
1908–1915 .	83·5	87·5	89·9	88·5	85·7	83·1	81·5	81·2	81·5	83·7	84·9	82·3	84·4
KEFFI													
8 51 N 7 52 E.	93·5	96·2	96·8	93·8	90·3	87·4	83·4	83·0	85·6	90·5	94·3	88·3	90·3
1290 ft. . .	63·4	64·5	69·0	72·2	71·3	70·6	70·0	70·6	71·9	69·3	63·1	60·1	68·0
1909–1912 .	78·5	80·3	82·9	83·0	80·8	79·0	76·7	76·8	78·7	79·9	78·7	74·2	79·1
OFFA													
8 09 N 4 44 E.	93·4	93·3	94·4	91·1	88·4	85·6	82·2	82·1	83·6	85·3	88·5	89·9	88·1
1400 ft. . .	68·5	70·8	71·8	68·9	70·3	69·5	68·6	68·4	69·1	69·1	67·9	64·4	68·9
1913–1915 .	80·9	82·1	83·1	80·0	79·3	77·5	75·4	75·3	76·3	77·2	78·2	77·2	78·5
WOMBA													
8 52 N 8 37 E.	92·9	94·4	96·3	93·9	90·5	87·1	83·7	82·2	82·6	88·7	91·6	92·3	89·7
1160 ft. . .	65·5	69·2	70·8	74·0	73·4	70·1	70·3	69·3	68·9	70·0	65·9	58·6	68·8
1912–1914 .	79·2	81·8	83·5	83·9	81·9	78·6	77·0	75·7	75·7	79·3	78·7	75·5	79·3
IBI													
8 11 N 9 44 E.	94·7	98·7	100·3	96·5	92·1	88·3	86·6	86·6	87·2	90·2	93·0	93·1	92·3
580 ft. . .	64·8	69·1	74·2	75·3	73·5	71·3	72·0	71·4	71·3	72·0	67·7	62·1	70·4
1909–1915 .	79·7	83·9	87·3	85·9	82·8	79·8	79·3	79·0	79·3	81·1	80·3	77·5	86·3
ABEOKUTA													
7 09 N 3 21 E.	90·3	92·5	94·2	92·3	90·0	86·9	84·4	84·5	84·9	88·9	90·6	89·6	89·1
225 ft. . .	72·1	75·2	76·4	74·9	74·5	73·4	71·6	70·1	70·7	69·2	70·6	70·8	72·5
1906–1915 .	81·2	83·9	85·3	83·6	82·3	80·1	78·0	77·3	77·8	79·1	80·6	80·2	80·8

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TABLE I. (*continued*).—TEMPERATURES IN NIGERIA.

Stations, Positions, and Periods of Observation.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
OLOKEMEJI	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7°25′N 3°33′E	94·3	96·3	94·7	92·3	90·4	86·8	83·6	83·7	85·4	88·5	92·0	93·5	90·1
280 ft. . .	68·6	72·6	72·1	72·7	71·9	71·4	70·9	68·6	70·6	71·1	71·5	67·9	70·8
1906–1915 .	81·5	84·5	83·4	82·5	81·1	79·1	77·3	76·1	78·0	79·8	81·7	80·7	80·5
IBADAN													
7 24 N 3 53 E.	92·1	95·5	95·2	92·6	90·0	87·0	84·6	83·1	84·6	87·8	89·7	91·4	89·5
660 ft. . .	60·5	67·6	68·1	68·8	67·6	65·9	65·1	64·8	65·6	66·0	67·3	67·1	66·7
1906–1915 .	79·3	81·5	81·7	80·7	78·8	76·5	74·9	73·9	75·1	76·9	78·5	79·3	78·1
OYO													
7 51 N 3 55 E.	93·4	95·8	95·0	91·4	90·2	86·2	82·9	82·1	84·1	86·8	89·5	91·5	89·1
1070 ft. . .	67·6	69·1	69·4	70·1	67·8	67·7	67·6	66·7	66·3	68·4	68·6	66·4	68·0
1907–1915 .	80·5	82·5	82·2	80·7	79·0	76·9	75·3	74·4	75·2	77·6	79·1	78·9	78·5
ILESHA													
7 39 N 4 47 E.	85·7	88·5	87·7	86·4	84·4	81·4	77·8	76·9	77·3	82·8	85·1	86·0	83·3
	64·5	66·8	68·8	67·7	67·8	65·4	65·8	63·4	63·7	66·3	66·5	66·5	66·1
1907–1911 .	75·1	77·7	78·3	77·1	76·1	73·4	71·8	70·1	70·5	74·5	75·8	76·3	74·7
ONDO													
7 06 N 4 50 E.	91·3	91·0	90·0	91·1	88·9	85·9	82·0	82·8	84·5	87·0	88·9	88·8	87·7
	67·9	69·8	71·7	70·9	69·8	70·5	70·1	68·4	68·1	69·3	69·1	68·3	69·5
1906–1915 .	79·6	80·4	80·9	81·0	79·3	78·2	76·1	75·6	76·3	78·1	79·0	78·5	78·6
LOKOJA													
7 48 N 6 45 E.	93·0	96·2	96·6	93·9	91·1	87·7	84·9	84·6	85·7	88·2	91·8	90·4	90·3
320 ft. . .	68·1	72·3	74·9	74·9	73·8	71·9	71·7	71·0	72·5	72·0	69·6	65·2	71·5
1907–08, 1910–15	80·5	84·3	85·7	84·4	82·5	79·8	78·3	77·8	79·1	80·1	80·7	77·8	80·9
ANKPA													
7 40 N 7 80 E.	89·8	91·8	92·8	89·6	86·7	84·1	81·9	81·1	82·2	84·6	88·1	89·2	86·8
750 ft. . .	68·5	70·7	70·7	71·3	70·8	69·5	68·7	68·5	67·7	68·8	66·7	64·9	68·9
1909–10, 1912–14	79·1	81·3	81·7	80·5	78·7	76·8	75·3	74·8	74·9	76·7	77·4	77·1	77·9
PORTO NOVO (DAHOMEY)													
6 28 N 2 40 E.	92·7	93·6	94·8	93·7	92·3	89·4	86·9	86·0	87·6	89·6	93·0	92·5	91·0
65 ft . . .	71·4	74·5	75·9	74·5	73·4	72·0	72·3	72·0	72·7	73·2	72·9	72·5	73·1
1897–1899 .	82·1	84·1	85·3	84·1	82·9	80·7	79·6	79·0	80·1	81·4	82·9	82·5	82·1
BADAGRI													
6 25 N 2 53 E.	86·5	86·4	87·6	86·5	86·0	83·5	81·6	81·0	81·6	83·2	86·0	86·4	84·7
9 ft. . . .	71·9	74·0	74·7	74·1	71·8	71·0	71·8	72·2	71·5	72·2	73·4	71·9	72·5
1907–1915 .	79·2	80·2	81·1	80·3	78·9	77·3	76·7	76·6	76·5	77·7	79·7	79·1	78·6
OTTA													
6 42 N 3 15 E.	87·4	88·5	89·5	89·1	87·5	82·0	80·5	81·8	82·8	84·8	85·8	87·8	85·6
	68·1	71·0	72·0	72·0	72·6	71·5	71·1	69·3	70·2	70·0	71·8	70·7	70·9
1906–1910 .	77·7	79·7	80·7	80·5	80·1	76·7	75·8	75·5	76·5	77·4	78·8	79·3	78·2
LAGOS													
6 27 N 3 24 E.	87·1	88·1	88·6	88·0	86·5	83·6	81·4	81·5	82·6	84·3	86·9	87·7	85·5
6 ft. . . .	74·9	76·1	77·3	76·7	75·9	73·6	73·4	72·8	73·5	74·0	75·7	74·9	74·9
1886–1900, 1906–1915	81·0	82·1	82·9	82·3	81·2	78·6	77·4	77·1	78·1	79·1	81·3	81·3	80·2
EPE												—	
6 35 N 4 00 E.	88·7	90·5	91·0	89·5	88·5	85·1	81·9	81·8	83·3	85·1	88·9	88·9	86·9
75 ft. . .	71·2	73·2	73·3	73·0	73·7	72·3	72·8	70·7	72·4	72·5	72·1	71·1	72·4
1906–1915 .	79·9	81·9	82·1	81·3	81·1	78·7	77·3	76·3	77·9	78·8	80·5	80·0	79·6

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TABLE I. (*continued*).—TEMPERATURES IN NIGERIA.

Stations, Positions, and Periods of Observation.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
OSHOGBO	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
7°45′ N 4°33′ E	90·7	92·1	92·4	90·9	88·7	86·7	81·9	80·4	84·5	86·7	88·5	90·0	87·8
1030 ft.	65·5	68·7	68·8	66·1	65·0	67·0	65·7	65·0	67·3	67·9	67·6	64·4	66·6
1907–1912, 1915	78·1	80·4	80·6	78·5	76·9	76·9	73·8	72·7	75·9	77·3	78·1	77·2	77·2
IFON													
6 54 N 5 47 E.	90·4	94·0	94·3	89·0	87·9	85·1	82·6	80·2	82·4	85·8	88·1	89·3	87·4
	64·1	72·4	72·7	71·1	70·1	68·8	68·4	67·8	69·3	69·1	71·1	67·0	69·3
1907–1908	77·3	83·2	83·5	80·1	79·0	76·9	75·5	74·0	75·9	77·5	79·6	78·1	78·3
BENIN CITY													
6 20 N 5 36 E.	88·2	89·8	90·5	90·3	89·9	86·9	83·0	83·8	83·2	86·7	88·4	88·5	87·4
370 ft.	63·5	65·8	66·4	67·2	65·7	65·4	64·5	64·0	64·4	64·9	65·0	63·8	65·1
1907–1915	75·9	77·8	78·5	78·7	77·8	76·1	73·7	73·9	73·8	75·8	76·7	76·1	76·2
ASABA													
6 12 N 6 44 E.	90·9	93·4	94·0	92·6	90·9	87·6	86·0	87·1	87·1	88·8	89·8	90·9	89·9
	68·0	71·5	71·9	72·6	70·1	69·6	69·4	68·6	69·2	69·9	69·2	65·6	69·6
1907, 1912–1915	79·5	82·5	82·9	82·6	80·5	78·6	77·7	77·9	78·1	79·3	79·5	78·3	79·8
ONITSHA													
6 10 N 6 47 E.	90·2	93·1	93·8	91·5	90·0	87·0	83·8	84·6	86·6	88·2	90·8	89·9	89·1
240 ft.	72·3	75·0	74·1	72·3	71·7	70·3	70·7	70·7	72·6	72·7	73·5	70·5	72·2
1907–1915	81·3	84·1	83·9	81·9	80·9	78·7	77·3	77·7	79·6	80·5	82·1	80·2	80·7
UDI													
6 14 N 7 22 E.	86·5	89·5	88·5	86·7	85·6	84·0	81·3	81·0	82·5	83·8	87·3	88·9	85·5
1235 ft.	72·8	74·0	73·4	72·7	71·3	71·4	69·1	68·9	68·6	69·7	70·9	72·9	71·3
1911–1915	79·7	81·7	80·9	79·7	78·5	77·7	75·2	74·9	75·5	76·7	79·1	80·9	78·4
OKWOGA													
6 59 N 7 45 E.	92·3	93·0	90·6	88·9	87·7	85·5	82·3	82·1	83·1	86·5	89·9	91·1	87·7
	67·5	70·7	70·3	71·4	71·0	70·4	70·5	69·5	70·3	69·5	69·7	62·9	69·5
1911–1915	79·9	81·9	80·5	80·1	79·3	77·9	76·4	75·8	76·7	78·0	79·8	77·0	78·6
OBUDU													
6 38 N 9 08 E.	91·0	92·7	93·5	90·7	87·6	85·3	82·6	82·2	84·0	85·8	88·0	88·9	87·7
	67·1	70·8	74·2	73·1	72·0	70·9	70·8	70·2	69·7	70·1	69·4	64·1	70·2
1913–1915	79·1	81·7	83·9	81·9	79·8	78·1	76·7	76·2	76·9	77·9	78·7	76·5	78·9
FORCADOS													
5 23 N 5 26 E.	90·2	89·0	90·4	90·4	88·0	84·7	82·3	82·8	83·0	83·5	87·0	88·7	86·7
	67·8	68·3	69·8	68·8	67·9	67·3	67·0	66·9	67·2	68·8	68·4	68·2	68·0
1907–1915	79·0	78·7	80·1	79·6	77·9	76·0	74·7	74·9	75·1	76·1	77·7	78·5	77·4
WARRI													
5 31 N 5 44 E.	90·3	91·4	92·6	90·2	91·6	89·8	85·6	84·9	85·6	88·5	90·8	90·6	89·3
	70·0	71·3	71·6	71·9	71·8	71·5	70·2	70·8	70·8	71·3	71·8	69·5	71·0
1907–1914	80·1	81·3	82·1	81·1	81·7	80·7	77·9	77·9	78·2	79·9	82·3	80·1	80·2
ABOH													
5 32 N 6 33 E.	90·2	92·8	92·3	91·9	90·9	88·5	85·6	85·0	85·1	87·3	89·6	89·4	89·1
	71·3	71·8	72·1	72·6	72·0	71·4	71·3	71·3	72·6	73·0	72·3	69·2	71·7
1907–1914	80·7	82·3	82·2	82·3	81·5	79·9	78·5	78·1	78·9	80·1	80·9	79·3	80·4
OWERRI													
5 29 N 7 03 E.	90·7	92·7	92·3	90·2	89·6	86·2	83·6	83·7	85·4	88·1	89·0	90·5	88·5
	65·4	68·8	68·8	69·4	68·9	68·5	69·7	68·8	69·1	68·2	68·6	64·9	68·3
1907–1915	78·1	80·7	80·5	79·8	79·3	77·3	76·7	76·3	77·3	78·1	78·8	77·7	78·4

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TABLE I. (*continued*).—TEMPERATURES IN NIGERIA.

Stations, Positions, and Periods of Observation.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
IKOT EKPENE	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
5°12′ N 7°43′ E	87·4	88·4	90·8	89·9	88·9	85·4	83·3	83·5	83·9	84·9	86·3	85·8	86·5
	66·8	70·9	70·3	69·3	69·5	70·2	69·4	68·6	68·8	68·9	69·2	66·5	69·0
1907–1915 .	77·1	79·7	80·5	79·6	79·2	77·8	76·3	76·1	76·3	76·9	77·7	76·1	77·8
BENDI													
5 34 N 7 37 E.	89·4	91·2	92·2	91·1	90·2	88·9	85·0	85·6	86·6	86·9	88·6	89·4	88·8
	68·6	69·1	70·5	71·0	69·9	69·8	70·4	71·3	70·4	71·6	69·5	67·0	69·9
1907–1909, 1913	79·0	80·1	81·3	81·1	80·1	79·3	77·7	78·5	78·5	79·3	79·1	78·2	79·3
AFIKPO													
5 53 N 7 55 E.	89·4	91·5	90·7	90·2	89·4	87·4	85·4	85·5	85·3	87·0	89·0	87·8	88·2
382 ft. . .	70·2	70·5	71·2	71·2	69·3	69·2	69·5	70·1	70·6	70·7	71·3	68·8	70·2
1907–1915 .	79·8	81·0	80·9	80·7	79·3	78·3	77·5	77·8	77·9	78·9	80·1	78·3	79·2
IKOM													
5 57 N 8 43 E.	90·4	91·1	92·7	91·6	90·7	89·9	87·2	86·1	88·0	88·9	89·8	88·8	89·6
	66·1	66·9	67·7	68·1	69·8	70·3	69·4	68·1	68·5	67·9	67·7	63·9	67·9
1910–1914 .	78·3	79·0	80·2	79·9	80·3	80·1	78·3	77·1	78·3	78·4	78·7	76·3	78·7
SAPELE													
5 55 N 5 42 E.	87·3	90·7	91·9	89·0	89·4	86·0	83·5	83·8	83·7	86·3	88·7	86·7	87·3
20 ft. . .	67·7	70·7	70·7	70·6	69·7	69·4	68·7	67·0	68·3	68·6	69·0	66·8	68·9
1907–1915 .	77·5	80·7	81·3	79·8	79·5	77·7	76·1	75·4	76·0	77·5	78·9	76·7	78·1
AKASSA													
4 19 N 6 03 E.	86·5	89·3	89·7	89·3	88·1	84·1	82·3	82·8	83·0	84·5	86·2	88·2	86·2
	69·8	71·1	69·9	69·5	70·4	68·3	69·7	69·2	68·7	68·2	69·4	69·2	69·5
1907–1914 .	78·1	80·2	79·8	79·4	79·3	76·2	76·0	76·0	75·9	76·3	77·8	78·7	77·8
BRASS													
4 18 N 6 14 E.	87·6	89·3	89·0	88·1	87·6	85·2	83·0	83·4	82·5	85·6	86·9	88·4	86·4
	72·0	73·8	73·1	73·8	74·1	72·3	72·0	72·7	71·5	72·3	73·0	71·7	72·7
1907, 1909–1915	79·8	81·5	81·1	80·9	80·9	78·7	77·5	78·1	77·0	78·9	79·9	80·1	79·5
DEGEMA													
4 45 N 6 47 E.	88·6	88·2	88·4	86·1	85·9	83·1	82·0	82·0	82·8	83·4	86·7	88·2	85·4
	75·4	76·3	76·1	74·1	74·6	73·3	72·6	72·4	71·4	72·5	74·2	74·4	73·9
1907–1915 .	82·0	82·3	82·3	80·1	80·3	78·2	77·3	77·2	77·1	77·9	80·5	81·3	79·7
BONNY													
4 27 N 7 10 E.	87·5	88·1	88·8	88·6	87·0	84·2	83·6	84·5	83·6	85·1	86·0	88·2	86·3
	71·2	71·8	72·5	71·0	70·7	70·2	69·7	70·0	68·5	69·4	70·0	70·9	70·5
1907–1915 .	79·3	79·9	80·7	79·8	78·9	77·2	76·7	77·3	76·1	77·3	78·0	79·5	78·4
OPOBO													
4 34 N 7 33 E.	88·2	90·0	89·5	90·5	89·9	86·2	84·7	85·1	83·9	85·6	86·8	87·7	87·3
	70·9	73·3	74·2	74·3	74·5	72·7	71·7	72·2	71·9	72·6	73·0	71·3	72·7
1908–1915 .	79·5	81·7	81·9	82·4	82·2	79·5	78·2	78·7	77·9	79·1	79·9	79·5	80·0
CALABAR													
4 58 N 8 19 E.	89·5	91·2	91·3	90·6	89·3	87·6	86·5	85·7	86·9	87·4	88·1	89·9	88·7
	71·6	71·9	72·6	72·3	71·7	71·0	71·1	70·2	69·4	69·5	70·9	71·2	71·1
1907–1915 .	80·5	81·5	81·9	81·5	80·5	79·3	78·8	77·9	78·1	78·5	79·5	80·5	79·9

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In connection with Fig. 2, the following Table (Table II.) is of interest as giving the latitude of the sun on the first day of each month.

TABLE II.—LATITUDE OF SUN.

First day of Sun's Latitude .	Jan. 23° S.	Feb. 17½° S.	March. 7½° S.	April. 4½° N.	May. 15° N.	June. 22° N.
First day of Sun's Latitude .	July. 23° N.	Aug. 18° N.	Sept. 8½° N.	Oct. 3° S.	Nov. 14½° S.	Dec. 22° S.

Figs. 3 and 4 show the means of the daily maxima in April and August respectively, *i.e.* at the close of the dry season and in the middle of the rainy

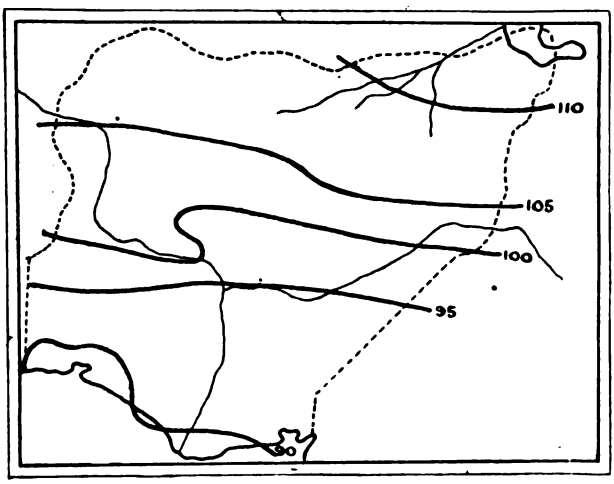

FIG. 3.—Mean Daily Maximum, April (reduced to Mean Sea-Level).

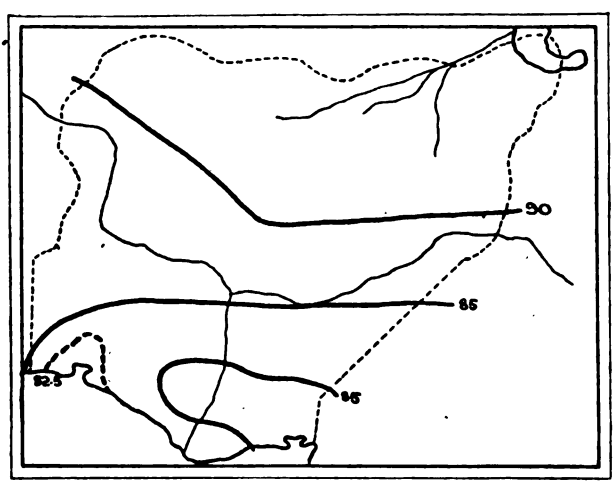

FIG. 4.—Mean Daily Maximum, August (reduced to Mean Sea-Level).

season. April (Fig. 3) shows the influence of the dry interior and land winds very markedly, the mean daily maximum increasing from below 90° F. near

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the coast to above 110° F. near Lake Tchad. In August (Fig. 4), on the other hand, with the rainy monsoon well established, not only are the maximum temperatures everywhere lower, but there is also a much smaller range from the coast to the interior. During this month the variation is only 13° F. (Lagos, 82° F.; Geidam, 95° F.), compared with 24° F. in April (Lagos, 88° F.; Maiduguri, 112° F.).

The mean daily minimum decreases inland during December and January,

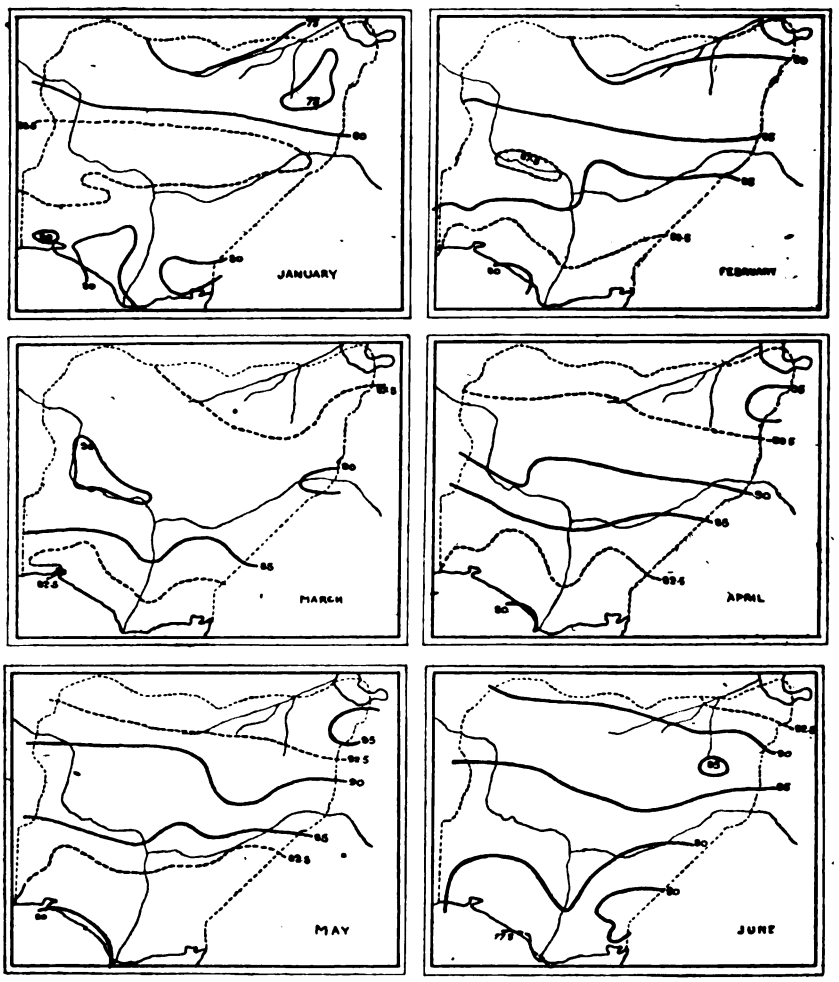

FIG. 5.—Mean Monthly Temperatures (reduced to Mean Sea-Level).

when it falls to 55° F. at Nafada, but at other times there is remarkably little variation throughout the country, the figures remaining persistently not far from 72° F.

Fig. 5 shows the temperature distribution month by month. In January the warmest part, above 82°·5 F., is a belt lying east and west across the centre of the Colony, while in the north the temperature is below 75°. Near the coast the temperature is everywhere close to 80° F., and this part of the area shows exceedingly little change through the year. In February and

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March the central belt and northern part of the Colony become steadily warmer, but the highest temperature (above 90° F.) is still found near Jebba. In April this distribution is changed, and the temperature rises steadily from the coast to near Lake Tchad (95° F.). This continues in May, but in June, with the incoming of the rainy season, a fall sets in, which is maintained until August, though the warmest area still lies near Lake Tchad.

In September there is a slight rise in the north, giving a secondary

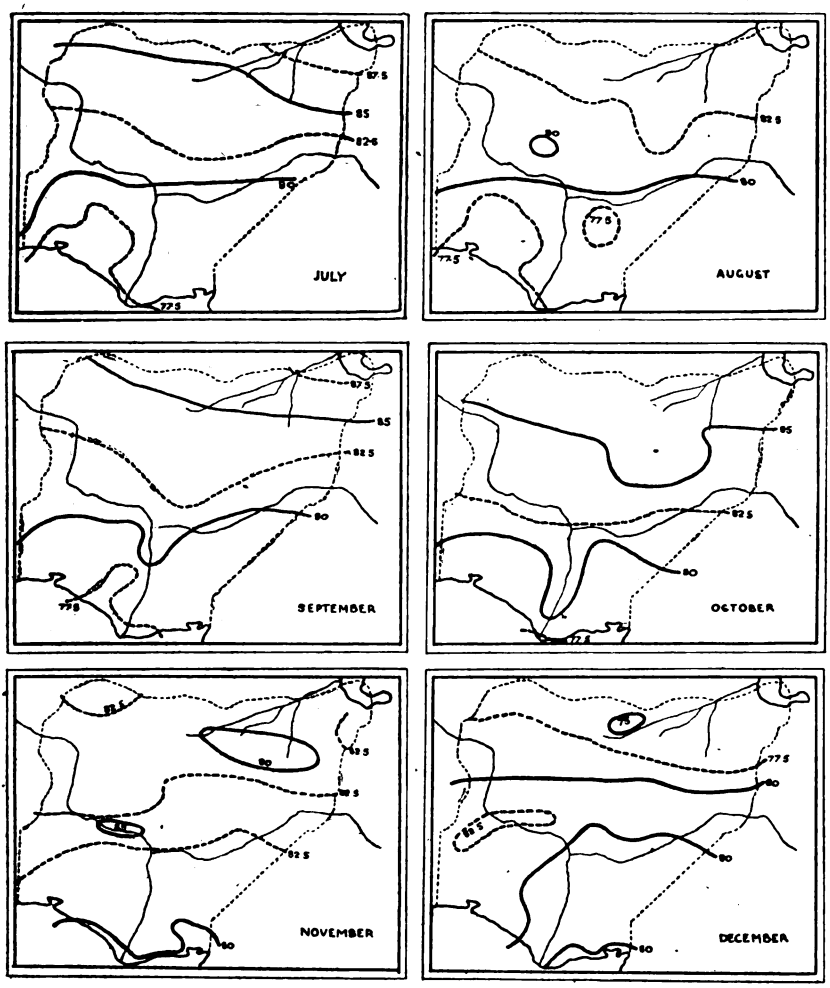

FIG. 5a.—Mean Monthly Temperatures (reduced to Mean Sea-Level).

maximum of about 87°·5 F., but in October a fresh fall sets in, and in November and December the belt of maximum temperature across the centre of the Colony is again developed.

Fig. 6 shows the annual variation of the mean daily maximum and minimum temperatures at four selected stations, from north to south: Sokoto, Zungeru, Lagos, Akassa. Sokoto, near the northern boundary of the Colony, shows a well-marked double oscillation of the mean daily maximum, with a primary maximum in April, and a secondary maximum in October and

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November, separated by minima in December and January (northern winter) and in August (rainy season). In the curve for the mean daily minimum the August depression and October maximum are almost obliterated, leaving only a single maximum in May, and minimum in December to January. The daily range thus oscillates between a maximum in January (dry season) and a minimum in August (wet season).

At Zungeru the secondary crest is almost suppressed in the curve of the daily maximum as well as in the curve of the mean daily minimum. Lagos shows a simple annual oscillation of both curves, with a maximum in March and a minimum in June; both the mean daily range and the annual range are

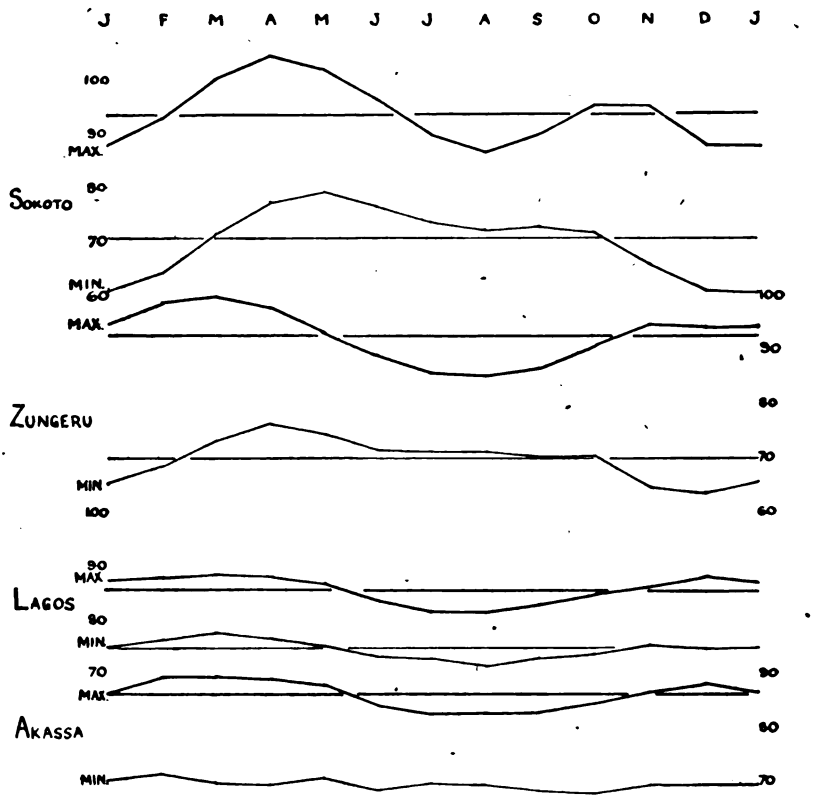

FIG. 6.—Annual Variation of Mean Daily Maximum and Minimum Temperatures.

here greatly diminished. Akassa, on the Niger mouth, shows a slight secondary crest at December in the daily maximum curve. The daily minimum curve is extraordinarily flat, having a total range of less than 2° F.; it cannot be said to show an annual range at all.

Throughout the note the mean temperature has been taken as the mean of the mean daily maxima and minima. This was necessary, as no data are available for calculating the correction necessary to reduce this mean to the value which would be given by the mean of hourly observations. By analogy with other stations in the tropics it probably ranges from about $-1°{\cdot}5$ F. on the coast to about $-0°{\cdot}5$ F. in the north of the Colony, that is, the isotherms read about $1°{\cdot}5$ too high in the south and about $0°{\cdot}5$ too high in the north.

C. E. PELHAM BROOKS.

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OBITUARY.

Mr. George Corden.

With regret we announce the death of Mr. George Corden, which occurred at his residence at Croydon on February 6.

Mr. Corden was born at South Norwood in 1840, but resided in Croydon from 1850. For 30 years he acted as dispenser to a firm of physicians and surgeons, and later served under the Croydon Rural District Council. In 1867 Mr. Corden took up meteorology, gradually acquiring an extensive set of instruments. These he observed most regularly for over 50 years, and accumulated a valuable record of the weather, to which reference was often made locally at abnormal periods. Mr. Corden was also a successful photographer and greatly devoted to music.

He was elected a Fellow of this Society on November 17, 1880.

Mr. G. H. Hill, M.Inst.C.E.

Mr. George Henry Hill, whose death occurred in December 1918, was one of the most eminent of the group of water engineers who took part in the noteworthy developments of the latter half of the nineteenth century. For seventy years he maintained his connection with the Manchester Corporation water services. During this period he designed and carried out the world-renowned Thirlmere scheme, by means of which the water supply for a population of about one and a half millions is maintained. Some of the most valuable rainfall records in the north of England, particularly in the Lake District, were commenced and supported by him.

He was elected a Fellow of this Society on November 15, 1893, and died at the ripe age of 92 years.

Mr. Harold Macfarlane.

On December 14, 1919, at his residence at Northwood, Middlesex, occurred the death of Mr. Harold Macfarlane from heart failure following an attack of pneumonia. Mr. Macfarlane was well known as a statistical writer, being the author of the statistical portion of the Oxford Survey of the British Empire. During the war he rendered valuable service in the meteorological branch of the Intelligence Department of the Admiralty, under the charge of Dr. H. N. Dickson, O.B.E. He also worked very strenuously as a Special Constable, which probably undermined his never very robust constitution and contributed towards his death.

He was elected a Fellow of this Society on December 20, 1916, and died in his 51st year.

REVIEWS.

Manuel Pratique de Météorologie. By Lieut. J. Rouch. *Paris* (Masson & Cie.), 1919. 8°. Pp. viii + 144, Pls. XIV. 6 f. 50 net.

In the introduction the author comments on some points emphasised by war experience in meteorology,—

(1) to utilise a forecast in a rational way one must know the reasons at the back of it,

(2) an anonymous forecast, sent by a Central Service, can inspire only a

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limited confidence : the commander of an army, a ship, or a squadron requires something more. Hence the necessity, for all who would derive guidance from the meteorologist, to understand the elementary ideas of Meteorology. Few will disagree with this reasoning, but he ventures later on more debatable ground when he states that two or three months will enable the novice to forecast weather with "ALMOST" as much exactitude as the specialist. Some might regard (say) 90 per cent of total and partial successes as "almost" as good as 95 per cent ; others, more discriminating, might call the latter twice as good as the former ; the military commander faced with operations of great magnitude would be more likely to value meteorological advice according to something like the inverse square of the probability of error.

The synoptic chart is made the basis of the teaching. The reader is assumed to be acquainted with the elementary notions of pressure, temperature, humidity, formation of clouds and rain, etc., as described in treatises on physics. The book does not fail to reproduce Abercromby's diagram and description of the moving depression. One is continually surprised to find this, especially in continental textbooks, for over the greater part of Europe the details cannot be regarded as even approximately representing the truth. For instance, in Belgium, North France, and Germany the actual facts are that rain is often slight and slow to commence in the right front, but heavy and remarkably persistent in the right rear of a depression. The author, however, does state that there are exceptions to the formerly accepted descriptions of the moving depression, and is particular to point out how many varieties of weather may be experienced in anticyclones. The chapter on fog and its formation and the remarks on haze and visibility are on sound, simple lines and well up to date. The same is true of the chapter on the upper atmosphere, which contains many welcome additions to an elementary textbook.

The book is written throughout with that lucidity and happiness of expression characteristic of many French scientific writers. A. H. R. G.

The Characteristics of the Free Atmosphere. By W. H. DINES, F.R.S. London, Meteorological Office, *Geophysical Memoirs*, No. 13, M.O. 220c, 1919, pp. 47–76. 2s. net.

In this *Memoir*, Mr. Dines gives in a convenient form a summary of the principal results obtained by investigation of the free atmosphere. Much of the information comes from scattered sources, and the tables in which it is summarised are, therefore, of special value. In these are given the mean temperature at different heights for different parts of the world, and the change in conditions with change of latitude is discussed. For the British Isles and certain other regions the seasonal range of temperature at different levels is considered. There is a small lag in phase from the surface up to about 11 km., but above this the time of minimum temperature falls back rapidly to the beginning of January at 13 km. over Europe. A maximum value of the amplitude of the annual range is found to occur at about 7 km. height. With a coastal climate the range at this level exceeds that at the surface of the earth, but this is not so in regions with a continental climate. Between the 9 km. and 12 km. levels the temperature range falls off rapidly. The diurnal range of temperature is also discussed, and it is found that this, in its surface form, ceases to be appreciable at between 1 and 2 km. height.

Pressure differences between one place and another do not exhibit much change between 2 and 10 km. height. Above 12 km. they fall off rapidly, until at 20 km. the pressure seems to be uniform over all those parts of the earth where observations have been systematically made. The various means by which cooling of the air in the centre of a depression and warming in the

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centre of an anticyclone can come about are discussed. It is demonstrated that the observed effects can be accounted for by adiabatic changes connected with air rising or falling through moderate heights in the two systems. A table of correlation coefficients exhibits the connection which exists between the different elements in the free atmosphere. With regard to the height of the base of the stratosphere it is shown that this height is regulated by the pressure at about 9 km. above the surface.

In the concluding paragraphs of the *Memoir* the efficiency of variations of humidity in causing the movements of the atmosphere is discussed. By the method of correlation it is shown that there is very little connection between the height of the stratosphere and the amount of water vapour below it. The water contents of the atmosphere are chiefly dependent on temperature, but the general result is to show that, so far as Europe is concerned, water vapour plays a very small part in the mechanics of the atmosphere.

Tropical Control of Australian Rainfall. By E. T. QUAYLE, B.A. Melbourne, Commonwealth Bureau of Meteorology, *Bulletin* No. 15. [1919.] 4°. Pp. 24, pls. 12.

This paper is concerned with the influence of tropical conditions on the development and rainfall production of storms in the temperate belt of Australia, and a method is described whereby both the accuracy and range of the forecasts of the winter rainfall in this belt are increased. It is intended to show that the rain-producing power of these southern depressions is dependent on their being fed by a flow of air from the tropical regions. This influence is traced by the somewhat novel method of plotting the departures from normal of the daily minimum temperatures at selected stations, the minimum temperature being chosen as responding readily to the changes in wind direction, humidity, and cloud which would mark the course of this tropical current. It is a matter for regret, however, that in the description of the interesting results obtained and their practical application to forecasting, the physical aspect of the subject is largely obscured.

A series of maps which is reproduced, showing the distribution of the mean monthly rainfall and minimum temperature departures over the Continent for the years 1911 to 1916, indicates in a general way that the areas of heaviest rainfall are related to areas of high minimum temperature extending to the north-west well into the dry tropical region. This relation is investigated more closely for particular cases, the most important being that in which the minimum temperature departures at Darwin and Mein, two stations in the extreme north, are correlated with the rainfalls of Northern Victoria and the Upper Darling district. Graphs are reproduced in the latter case for the years 1911 to 1918, the chief points on which emphasis is laid being that the plus and minus minimum temperature departures at the northern stations persist for considerable periods averaging over three weeks in length, and that the heaviest southern rainfall follows the entry upon a plus period. It cannot be said that the graphs are exactly convincing, while in the series illustrating an earlier and similar investigation in which the minimum temperature departures of stations much farther south are plotted, this is even more emphatically the case. It is explained, however, in regard to the latter that the minimum temperatures were affected by depressions passing to the south, so that the periods of plus and minus departure referred to could not be easily identified. But if the graphs are not particularly convincing, the numerical results, which are set out very clearly, are most striking. Those relating to the Upper Darling and Northern Victoria show that the average daily rainfall is more than twice as great during periods when the minimum temperature at Darwin is above

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normal as when it is below, and also that the higher the temperature the heavier is the rainfall. The practical application of this interesting result is that the forecaster, having ascertained that a period of plus departure has been entered upon at Darwin, can predict with fair confidence that the rainfall in the southern districts during the next two or three weeks will be well above the average.

A further point brought out, among others, is that the minimum temperature periods at Darwin follow those at Mein, some eight hundred miles farther east, by an interval averaging two and a half days, which indicates an east-to-west drift of what the author somewhat vaguely terms "tropical weather influences." This, he points out, shows the possibility of looking to the neighbourhood of New Guinea for the first indication of most of the Australian rains. The paper is full of interest, but if more stress were laid on the physical significance of the results arrived at, its value would be greatly enhanced. F. ENTWISTLE.

Pression atmosphérique en Pologne et en Europe. Warszawa, 1917, pp. 265. 4°.
Nouvelles isothermes de la Pologne, de l'Europe et du Globe terrestre. Warszawa, 1918. Pp. 286. 4°. Polish, with résumé in French. By W. GORCZYŃSKI.

These two books, dealing in great detail with the pressure and temperature of Europe, can only be the work of an enthusiast, who must have been engaged continuously in their preparation and publication at Warsaw all the time that the war was raging round him. Much of the calculation must have been done within sound of the guns. Unfortunately they are betrayed as the work of an enthusiast in another way, for among the great mass of figures of which the author has made use are many which a more critical examination would have rejected as unsound.

In spite of this defect the books are very valuable contributions to meteorology. The author realises and insists upon the necessity of employing a uniform period as the basis of his maps of isobars and isotherms. Recent meteorological work is showing more and more that long slow changes of climate are in progress in most parts of the world, and that for example the mean pressure for the period 1851 to 1900 may differ appreciably from the mean for the period 1886 to 1910 at the same station. The period selected as a standard is the half-century 1851 to 1900; for these years the author makes use of 51 stations in the case of pressure and of 26 in the case of temperature. By means of these standard stations several hundred shorter records have been corrected to the standard period in the usual way.

This, at least in the case of pressure, is where the author's enthusiasm carries him away. In the case of Scotland alone, for example, he has adopted one hundred and fifty stations direct from a work by the late Dr. A. Buchan.[1] These stations, many of which must be based on very short periods, were corrected by Buchan to the forty-year period 1856 to 1895, and re-corrected by Gorczyński, using in some cases different standard stations for comparison, to the period 1851 to 1900. One can but think that one-tenth the number of stations in Scotland, well chosen and well distributed, would have been more useful for map-drawing. The same procedure has been applied to records for other countries. The method of reducing a short series to a long one by differences is admirable in itself, but its repeated application to the same set of figures must be condemned.

The means calculated for certain isolated stations must often be regarded as

[1] The mean atmospheric pressure and temperature of the British Isles. *Edinburgh, J. Scot. Meteor. Soc.*, 11 (ser. 3), 1898.

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doubtful. As an example, the mean pressures for Thorshavn (Faroe Is.) have been taken from Rung's well-known work. These figures refer to the fifteen years 1881 to 1895 and have been corrected to the fifty-year period by comparison with Stykkisholm in Iceland. Bearing in mind that the station at Thorshavn commenced in 1871 and is still in existence, and that the two stations are about five hundred miles apart, it seems probable that the period 1851 to 1900 at Thorshavn is better represented by the mean of 1871 to 1915 than by the corrected mean for 1881 to 1895, especially in the summer months, when the correlation between the two stations is slight.

The pressures at Stykkisholm are stated to be "mean of 24 hours," but when the statement was traced back to its original sources it was found to rest on a casual remark of Hann's that as the diurnal range is small no correction need be applied. As the hours differ in different parts of the series, this point might with advantage have been made clear.

For Central Europe and specially Poland the author's work seems sufficiently reliable; here the reductions have a safe basis and the maps of isobars and isotherms should be adopted as at present the best available, joining on with Angot's in France for the same period.

Both volumes contain much matter of interest aside from their main object, and the work on temperature closes with a curious little sketch of the climatology of Poland from the point of view of political independence.

C. E. P. BROOKS.

Meteorology for All, being some weather problems explained. By DONALD W. HORNER, with an introduction by M. de Carle S. Salter. London (Witherby & Co.), 1919. 8°. Pp. xvi + 184, pls. 6s. net.

This little book is of a popular character and will appeal to those who merely wish to know what the weather is doing as well as to those who keep an accurate record. A feature of the book is the very large number of illustrations of instruments, including not only the usual standard ones and many self-recording instruments, but also a number of a more popular kind such as wheel barometers, aneroids of different patterns, garden thermometers, and some which can scarcely be classed as meteorological, such as clinical and bath thermometers. On the other hand the explanation of weather problems as claimed in the title is not very seriously attempted. Synoptic charts are dealt with shortly, but the weather map hardly takes so important a place as might be expected at the present day, and some empirical rules for the use of the barometer in forecasting would be easier to follow if they were related to the moving systems of weather.

One chapter dealing with the C.G.S. units is of a more scientific order and is based largely on Lt.-Col. Gold's paper, read before the Society in 1914.[1] But the author's preference is for an aneroid, and he manages to convey the impression that in addition to requiring no temperature correction, it has the further advantage of a simpler process of reduction to sea-level. Mr. Dines's instruments for investigation of the upper air are illustrated with a short account of the methods employed, but the "relation to aviation," which appears as a chapter heading, is not worked out.

[1] Gold, Ernest. "Barometer readings in absolute units and their correction and reduction." *London, Q. J. R. Meteor. Soc.*, **40**, 1914, p. 185.

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NEW PREMISES.—The Council regret to have to report that the negotiations referred to on p. 187 relating to the provision of housing accommodation at 38 Grosvenor Gardens have fallen through.

April 21, 1920.

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QUARTERLY JOURNAL

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CLOUDS AS SEEN FROM AN AEROPLANE.

By CAPTAIN C. K. M. DOUGLAS, B.A., F.R.Met.Soc.

[Synopsis of a Lecture delivered before the Royal Meteorological Society, March 17, 1920.]

A SERIES of photographs will be shown on the screen this afternoon which will illustrate, firstly, the appearance of the clouds from above; and, secondly, the relation of the forms of the clouds to the distribution of temperature and humidity in the upper air, and to the local weather and general meteorological conditions. The photographs were taken in conjunction with observations of temperature and humidity at different heights, from fully exposed dry and wet bulb thermometers on the wing strut of the aeroplane, and also from self-recording instruments.

It is not generally realised that when the sky is covered with a gloomy canopy of cloud, with the inevitable smoky haze over towns and for a considerable distance to leeward, one has only to ascend about a mile in order to enter a region with clear blue sky above, and a sea of white billowy cloud underneath, which stretches in all directions to a distant horizon which stands out sharply owing to the perfect visibility.

Until recently almost the only method of getting above the clouds was by the slow and laborious process of climbing a mountain, and from the mountains of this country a view of the upper surface of the clouds is comparatively rare. A fair number of instances were recorded at the Ben Nevis Observatory, but most of them were in winter or in the early morning. In many cases when the level of the cloud-sheet is just below the top of the mountain, the sheet rises to cross the mountain and covers up the top.

The aeroplane now provides a much simpler means of getting above the clouds. A modern high-powered machine will climb up through several thousand feet of cloud in a very few minutes. In the cloud one is surrounded by thick fog which covers the machine with water, or with ice if the temperature is below the freezing-point and the cloud consists of super-cooled water-drops. Very soon, however, it grows lighter up above, and shortly afterwards one breaks out into clear sunshine. On some occasions there are other layers of cloud up above, but in anticyclones at any rate there is usually only a single sheet.

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I carried out observations of clouds from aeroplanes since 1915, but got very few opportunities of taking photographs. It was impossible to carry out cloud photography when flying on the line. But in the summer of 1918 I took over the flight which was obtaining upper air data for the meteorological section R.E. at G.H.Q. There was then a unique opportunity of obtaining cloud photographs. The necessary apparatus was already available, having been issued to the flight at the request of Lt.-Col. Gold. The camera used was one of the older patterns of R.A.F. hand cameras which proved suitable for the purpose. The plates available were the very fast panchromatic used for trench photographs and slow process plates used chiefly for copying. We found it difficult to avoid over-exposure with the fast panchromatics, and also found that they tended to get fogged as they had no paper on their backs, not being meant for taking bright objects. We found the process plates very suitable for bold cumulus clouds or rippled sheets of cloud. Some types, however, we never photographed successfully. We had no opportunity of carrying the photography to a fine art, as has been done by Capt. C. J. P. Cave and by Mr. G. A. Clarke of Aberdeen Observatory. It is possible to obtain quite good cloud photographs from an aeroplane by using Kodak films. The author obtained some photographs with Kodak films in England in the autumn of 1917, which were reproduced in the *Journal* of the Scottish Meteorological Society.[1] The best of these photographs illustrates the capabilities of a Kodak camera for cloud photography, when the lens is well stopped down and the right exposure given.

The flights were carried out twice daily in all types of weather in order to obtain upper air temperature for the artillery and forecasting. There were thus fairly frequent opportunities of taking photographs of clouds from above, but the photography was merely an extra. If ascents were made primarily to obtain cloud photographs, they would not be made at fixed hours, but when the clouds looked suitable for photography. In summer the clouds are usually most striking about the middle of the day, or early in the afternoon.

The photography was started in the middle of July 1918, and within ten weeks nearly a hundred good negatives had been obtained. Some further photographs were taken in the winter, but the clouds then have less variety than in summer. The majority of the photographs were taken by the author, but a number of good ones were also obtained by Lieut. R. V. Sessions, R.A.F., including Figs. 7 and 14 of those which are being reproduced. The photographs were taken from the pilot's seat, as we did not as a rule take up passengers. They were all obtained over or near Berck, on the French coast about twenty miles south of Boulogne. The locality is of interest from the meteorological point of view, and also because the area under observation included the Channel, which is important for commercial aviation. The coast-line runs from north to south from Cape Grisnez to the mouth of the Somme, a distance of fifty miles.

In winter the sky is very frequently overcast with a single sheet of low cloud varying in thickness from 500 to 2000 feet. This type of cloud is very characteristic of anticyclonic weather. There may be

[1] Vol. 17, ser. 3, 1917, pp. 133-147.

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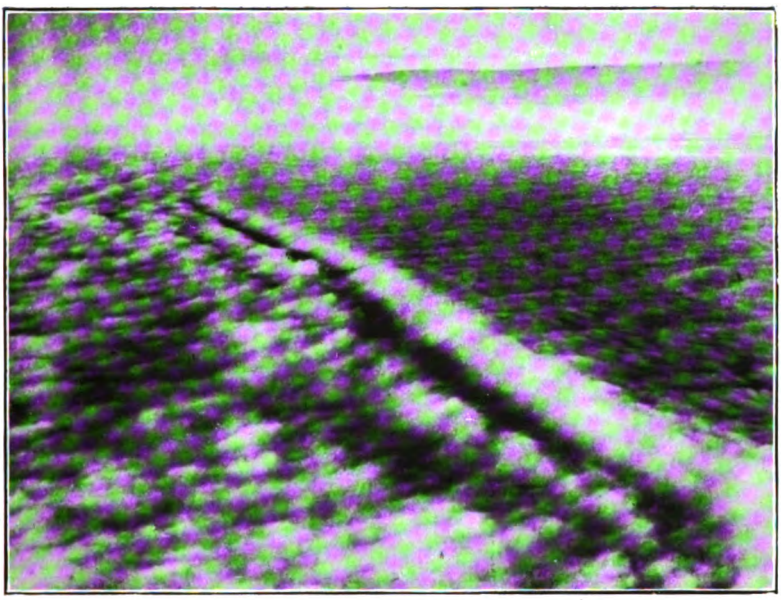

FIG. 1.—February 2, 1919, 15 h. A bank from SE to NW in a sheet of strato-cumulus cloud at about 4000 feet, moving from ENE.

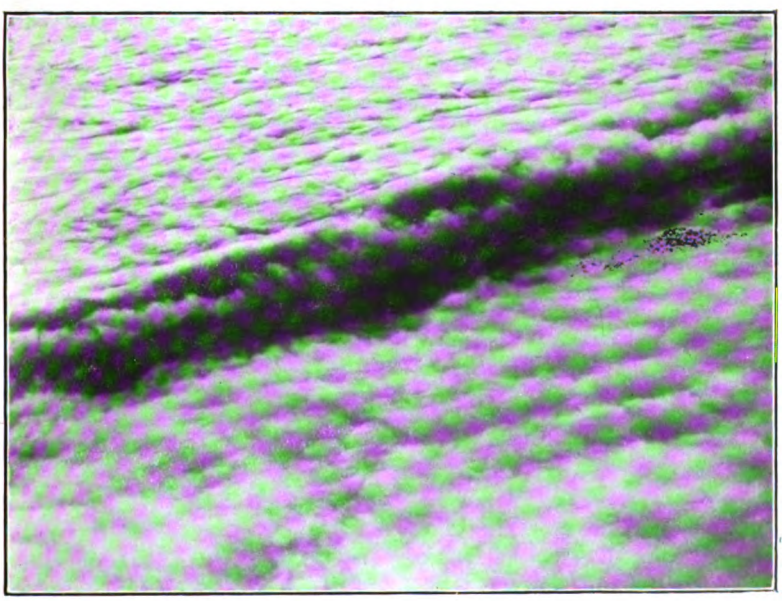

FIG. 2.—Another bank a few miles away at about the same time, in line ESE to WNW.

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FIG. 3.—February 3, 1919, 15 h. A typical rippled sheet of strato-cumulus cloud, with its upper surface 2500 feet.

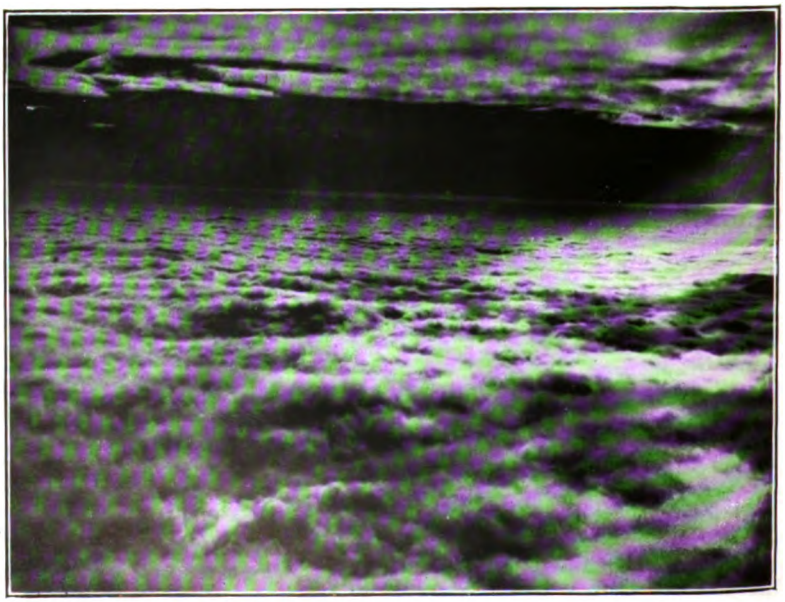

FIG. 4.—February 20, 1919, 10 h. Strato-cumulus below at 3000 feet, and other clouds above.

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several days or a week of overcast sky, a state of affairs described by Mr. W. H. Dines as "anticyclonic gloom." The same type of cloud is characteristic of Easterly winds in winter, with an anticyclone to the north. There was a spell of gloomy weather with East winds from January 29 to February 3, 1919. On January 29 there was a belt of high pressure from the Atlantic to the southward of Iceland, across Scandinavia to the Baltic. This belt moved south and decreased in intensity, and on February 3 the remnant of the anticyclone lay across England. The photographs reproduced in Figs. 1 and 2 were obtained on the afternoon of February 2, and that in Fig. 3 on the following afternoon. The first two photographs show parts of two separate banks in the cloud-sheet, each about 700 feet high, and with hollows underneath them, with some spaces through which narrow strips of the ground could be seen. The clouds were moving from ENE, and their base was at 3000 feet. The upper surface of the portion of the cloud-sheet seen on the right of the first photograph was at 5000 feet, but that on the extreme left was as low as 3800 feet, as though the cloud level rose somewhat immediately to the south-west (the left as seen in the picture) of the hollow below the bank, it sloped down again still further to the south-west. Some miles to the south-west there was a rather similar but more vertical bank, facing NNW and 700 feet high, and the cloud level was at 4500 feet on the south side of it, and at about that level to the horizon. Fig. 2 shows a portion of this bank. The total length of each bank was over twenty miles; the portion seen in Fig. 1 was over ten miles long. They were not quite parallel but formed an angle with its apex towards the south-east. Neither bank could be traced as far as the apex. The cause of the banks is not clear; their formation may have been connected with the fact that the current carrying the cloud-sheet had crossed a ridge of high ground and then descended to the coast. When the photographs were taken the banks were over the sea, moving along with the cloud. Mr. G. A. Clarke at Aberdeen Observatory is familiar with long narrow strips of blue sky in the middle of the clouds, and with banks of cloud with straight edges such as would be visible from the ground if the lower part of the clouds shown in Figs. 1 and 2 were absent.

Fig. 3 shows a very typical rippled sheet taken on the following day. The clouds were from 1000 to 2500 feet, lower than on the previous day. The ripples were across the North-east current, but not necessarily exactly at right angles to it. The photograph was taken from about a thousand feet above the clouds, looking towards the south-west. A photograph, taken from higher up and looking west, reproduced in *Symons' Meteorological Magazine* (January 1920) shows a very long ridge in the background not unlike those on the previous day, though only two or three hundred feet high.

The wind was measured above the clouds on February 2 by flying through a line of smoke shells burst at given intervals at the same place. No other upper wind observations were obtained on either the 2nd or the 3rd, even below the clouds, as there was a very thick haze, owing to smoke which had drifted from Germany and Belgium during the preceding few days. On the 3rd the upper wind had certainly backed somewhat towards North. The following are the observations of temperature and wind in

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the upper air corresponding to Figs. 1 to 4. The heights refer to the true height above the ground, the altimeter readings being corrected for temperature.

Date and Time.	Height (feet).	0.	1,000.	2,000.	4,000.	6,000.	8,000.	10,000.
Feb. 2, 15 hr.	Temp. ° F.	32	29	25	23	23	19	13
	Wind (Dir.)	...	...	...	...	ENE	...	ENE
	,, (Vel. m.p.h.)	...	...	...	...	18	...	17
Feb. 3, 15 hr.	Temp. ° F.	29	25	24	27	20	...	...
Feb. 20, 10 hr.	Temp. ° F.	51	49	45	40	35	26	20
	Wind (Dir.)	S by E	S	S	...	...	...	...
	,, (Vel. m.p.h.)	10	32	36	...	...	...	...

There was a rise of temperature above the clouds on February 2 and 3, as is usually the case. On February 2 temperature rose 2° as the machine climbed out of the thin part of the cloud at 3700 feet, and a further 2° at 4500 feet. Five hours earlier there was an inversion of 10° F. above the cloud-sheet, the temperature rising from 16° at the top of the clouds at 4300 feet to 26° at 4800 feet. On February 3 there was an inversion of 4° immediately above the clouds at 2500 feet, but on the 20th there was no inversion. On this occasion there was a warm Southerly current and low pressure, a deep depression being centred off SW Ireland. The photograph was taken towards the east, and the ripples lie along the direction of the wind rather than across it. It was quite a thin sheet at 3000 feet, and was not perfectly level. Up above there were other clouds at 8000 feet, the shadows of which are seen on the lower sheet. Thicker clouds from 6000 to above 12,000 feet came over soon after and caused showers. It will be noted that although there was no inversion above the lower clouds, the lapse-rate of temperature above them was stable even for saturated air. Unless this condition is fulfilled, the clouds are unlikely to remain long in the form of a horizontal sheet. These horizontal sheets may be met with in most types of weather, but are commonest in quiet anticyclonic weather.

A description of the method of development of these cloud-sheets is given by Sir Napier Shaw in the *Manual of Meteorology*, Part IV.[1] There is a system of eddies up to the top of the cloud-sheet which keeps up a supply of moisture from underneath, which is cooled as it is diffused upwards and condenses into cloud. A note from Mr. W. H. Dines is also included which emphasises the importance of radiation first from the damp layer where the clouds form, and later from the cloud itself. In a period of overcast weather in winter it is plain that there must be a good deal of radiation from the cloud. Even in quiet weather slight bumps are met with below and in the cloud, so that eddy motion is probably the most important factor in maintaining the cloud-sheet. Both eddy motion and radiation no doubt play a part in the development of inversions, but the chief factor in the production of large inversions would appear to be the presence of air above the clouds which

[1] Chapter v. p. 48.

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has descended *en masse* and been dynamically warmed. The relative humidity at the top of the inversion is usually below 40 per cent, occasionally below 20 per cent. Except close to the surface, large inversions are limited to anticyclones and to the regions just outside their boundaries. Inversions of as much as 15° F. in 500 or 1000 feet may exist at about 4000 to 6000 feet in winter, when air has descended down to the inversion, and the lower air was drawn originally from a cold source. If the lower cold air passes over a relatively warm sea clouds are particularly certain to develop under the inversion. In spells of cold East wind it frequently happens that the weather is overcast in the east of Great Britain but fine on the Continent. During the period January 29 to February 3, 1919, the weather was overcast over a large area on the Continent also.

The theory that the inversions of anticyclones are due to the upper air having been dynamically warmed by descent was put forward by Mr. W. H. Dines in 1911.[1] The air descending does not usually reach the ground, but may travel horizontally at 4000 feet or higher. In Southerly currents the descending air reaches a low level and much of it probably reaches the ground, being mixed up with the lowest layer by mechanical eddy motion and by convection in summer. In Northerly currents the inversion is usually above 5000 feet. Near the east and north-east boundary of an anticyclone it is often above 8000 feet, occasionally above 10,000 feet. The highest cloud layer shown in Fig. 5 was up to 9800 feet, and there was an inversion of 3° in 500 feet above it. This layer was only 100 to 200 feet thick, but another thicker layer from 7000 up to 9000 feet may be seen in the foreground through a gap in the top layer. There was another gap in the distance, but the upper layer was renewed towards the horizon, and in places clouds had broken through from below and exceeded 11,000 feet, which may be seen in the photograph. Note the folds in the cloud in two directions, crossing in the middle of the picture. The camera was pointing towards the north-west. Of the upper wind observations given below, those from 6000 to 15,000 feet were obtained from anti-aircraft shell bursts (single mirror method) about two hours earlier, before the sky was overcast. There were some cumulus clouds at 1500 feet which grew up to the upper layer locally inland, reaching 11,000 feet or so, and some local showers.

There were depressions over the North Sea and Iceland, a shoulder of high pressure over Ireland, and an extensive anticyclone to the south-west. The relatively warm and drier air above 10,000 feet had probably been carried forward from the shoulder of high pressure by the upper wind at those heights, which was stronger than the wind at 6000 feet. Next morning, when the shoulder of high pressure lay over northern France and southern England, about 300 miles further east, the inversion was at 5000 feet, and the relative humidity was about 30 per cent from 7000 to 8000 feet.

The upper air temperatures, humidities, and winds for August 26 and 28, corresponding to Figs. 5 and 7, are given below. The humidity figures in italics were obtained from the hygrograph records, the wet

[1] W. H. Dines. "The vertical temperature distribution in the atmosphere over England, and some remarks on the general and local circulation." *London, Phil. Trans. R. Soc.*, **211**, (ser. A.), 1911, pp. 253–278.

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bulb having dried up. The other humidities were obtained from the wet bulb readings, and gave good agreement with the hygrograph readings, making some allowance for the lag of the latter instrument.

Date and Time.	Height (feet).	0.	1,000.	2,000.	4,000.	6,000.	8,000.	10,000.	11,000.	12,000.	13,500.	15,000.
August 26, 1918, 18 hr.	Temp. ° F.	62	56	54	47	38	30	26	...	23	19	...
	R.H. %	82	93	86	73	91	100	76	*75*	*70*	*60*	...
	Wind (Dir.)	...	W by S	W by S	...	WNW	...	W by N	...	...	...	WNW
	,, (Vel., m.p.h.)	...	39	37	...	22	...	32	...	...	...	34
August 28, 1918, 8 hr.	Temp. ° F.	...	56	52	48	40	34	28	29	...	...	...
	R.H. %	...	93	86	79	92	89	50	22	...	...	...
	Wind (Dir.)	...	W by N	W by N	...	...	...	...	...	...	...	...
	,, (Vel., m.p.h.)	...	30	30	...	...	...	...	...	...	...	...

Fig. 7 shows the top of a large cumulus protruding rather more than 2000 feet through a cloud-sheet with its upper surface at 8000 feet. The base of the cumulus was at 2000 feet, and that of the cloud-sheet at 6000 feet. This protrusion of the tops of cumuli above cloud-sheets is very common inland on summer days, but if there is an inversion above the clouds the cumuli do not stand out so boldly above as in the example shown in the photograph. Nevertheless large cumuli may ultimately grow a thousand feet or even more above clouds with an inversion of 3° or 4° F. above them, the top of the cumulus being wider and flatter than that of Fig. 7. The cumulus had reached an inversion at 10,500 feet and did not grow much higher. The inversion was unusual considering that there was a well-marked depression centred over the North Sea with the trough right over NE France. An inversion at that level or higher is occasionally met with just behind the trough of a depression, due to a cold current flowing under a warm damp current, but it does not persist long, the cold current soon prevailing up above also. In this instance the air was dry above the inversion, which still persisted in the evening and amounted to 4° F., though the actual temperatures were rather lower. Next morning, when Berck was at the boundary of a large anticyclone to the south-west, the inversion amounted to 6° at about 11,000 feet. In the evening the inversion was at 8000 feet, but on the following day (Aug. 30) it was again at 11,000 feet.

There were some showers in NE France on August 28, and a little local thunder. No thunderstorm of any intensity will develop unless the clouds can grow up to a considerably greater height than 11,000 feet.

The forms assumed by the clouds over the land on summer days present a more complex problem than the cloud-sheets in winter or over the sea, which tend to drift for great distances without much change of form. If the temperature is low at 6000 to 8000 feet and there is plenty of moisture in the lower layers, cumulus clouds are sure to form, and if there is an inversion above the cold layer they spread out into strato-cumulus, so that the clouds are thicker over the land than over the sea. Sometimes it is cloudy over the land during the day and fine over the sea. On the other hand, if there are low clouds and very dry air above them at 3000 or 4000 feet, the clouds over the land during

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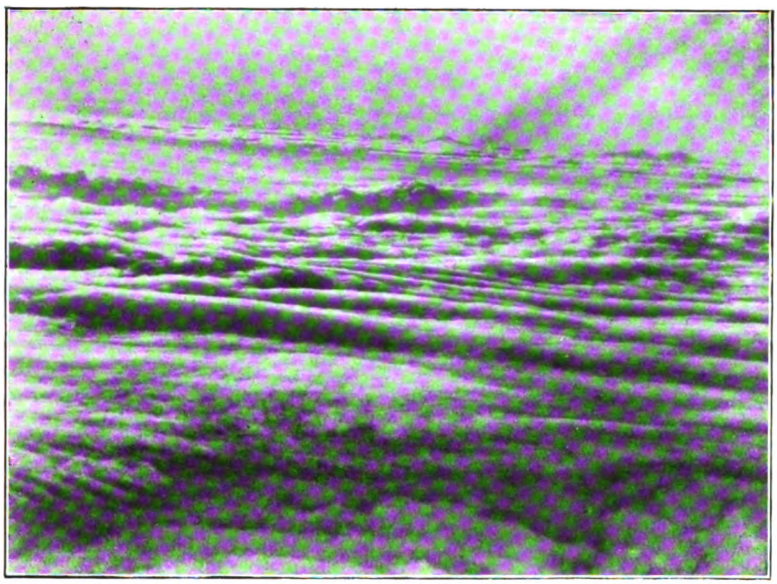

FIG. 5.—August 26, 1918, 18 h. Cloud-sheet at 10,000 feet, with ripples in two directions.

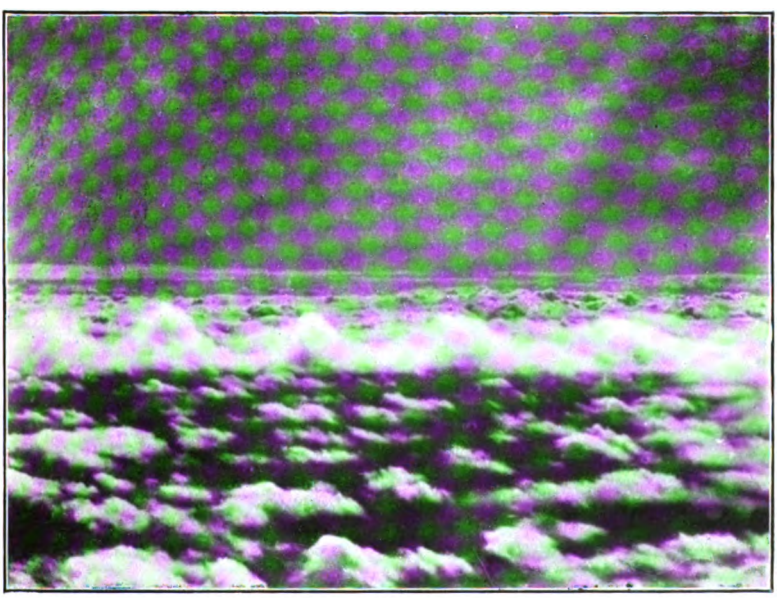

FIG. 6.—September 15, 1918, 10 h. A rippled strip of cloud at 4000 feet. Detached clouds below at 1000 to 1500 feet.

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FIG. 7.—August 28, 1918, 8 h. Top of cumulus protruding over 2000 feet through cloud-sheet, with upper surface at 8000 feet.

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FIG. 8.—September 13, 1918, 9 h. Tops of cumulus and strato-cumulus clouds up to 7500 feet in background. Strip of cloud at about 5000 feet in foreground.

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FIG. 9.—September 24, 1918, 7 h. Tops of recently formed clouds of cumulus type up to 5000 feet, extending about ten miles inland. Note haze horizon.

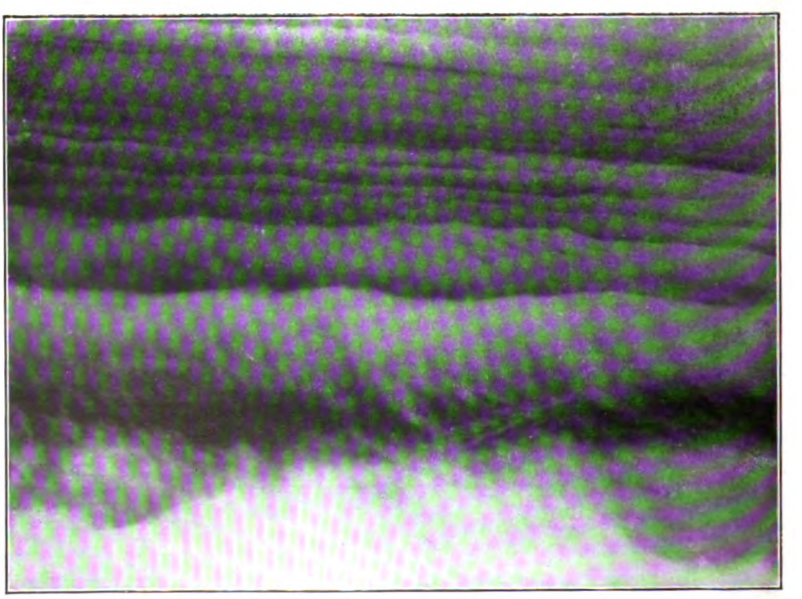

FIG. 10.—September 26, 1918, 18 h. Parallel belts of cloud at 3500 feet over the Channel. The distance between successive crests was about two miles.

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the day tend to get mixed with the dry air and dissolve away entirely. A thick low cloud-sheet with a large inversion above it may persist over the land for a day or two even in midsummer, but in time it nearly always gets dissolved away. There is a well-marked diurnal variation in the height of all types of clouds in summer over the land, the level of the base rising during the day, owing to the lower air being mixed with drier air above. The same process causes the level of the base of the clouds to rise as they drift inland from the coast, except in rainy weather.

Various types of summer clouds are illustrated by Figs. 8, 9, and 11 to 13. Fig. 8 (September 13, 1918) shows the tops of cumulus and strato-cumulus clouds which reached an inversion of 3° at 7500 feet. In the foreground the cumuli had only reached 5000 or 6000 feet, and a long strip of cloud had formed just above the tops of the growing cumuli, some of which were beginning to pass up through it. Such flat strips or patches of cloud frequently form above growing cumuli when the humidity is high, and ultimately become absorbed into the cumuli. The upward current within the cumulus cloud appears to cause the layer above it to bulge upwards.

Two days later the photograph reproduced in Fig. 6 was obtained in different meteorological conditions, an anticyclone having moved east from the Bay of Biscay to Switzerland. The lower clouds were the remains of a fog layer which drifted in from the Channel on the previous evening, and which persisted most of the day over the Channel and the coast near Boulogne. Over the land the clouds broke into cumulus, which ultimately reached 4000 feet, though those shown in Fig. 6 were at 1000 to 1500 feet, with an inversion of 2° above them. The rippled strip was at 4000 feet, and there was an inversion of 3° above it. The upper winds given below were observed nearly fifty miles away in an ESE direction, no observations being available locally. As the temperature at 4000 feet was 2° F. warmer a few miles to the south-east than in the neighbourhood of the cloud strip, it seems probable that in that locality the SW wind was stronger just above 4000 feet than just below it, and this increase of wind, together with the slight decrease of density, probably accounted for the ripples. The strip was approximately parallel to the wind and the ripples at right angles to it. There was much cloud at 4000 feet to the north-west, but little to the south-east, except the strips shown in the background in the photograph.

Fig. 9 shows clouds of cumulus type with their tops at about 5000 feet, looking east from the coast at Berck on the morning of September 24, 1918. The base of the clouds was at about 1500 feet, and they were nearly continuous, presenting the form of strato-cumulus as seen from the ground. The clouds formed over the sea and became larger and more continuous over the land. At the time that the photograph was taken they had only extended about ten miles inland, and further east there were only a few clouds. This may be seen from the photograph, which also shows a haze horizon at 5000 feet. There was no inversion at that height, but there was no fall in the temperature between 5000 and 6000 feet. The humidity was fairly low above 5000 feet, and during the day the dry air became mixed to some extent with the damper air below, with the result that the day was fair, with only detached clouds covering less than half the sky for the most part. In the evening the base of the lower clouds was at 3000 feet.

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The cumulus clouds on the morning of September 27 (Figs. 11 to 13) assumed a rather peculiar form. The base of the clouds was at 2000 feet, and most of them had not yet penetrated above 3000 feet. Some of them, however, entered a layer between 4000 and 7000 feet where the lapse-rate of temperature was decidedly above the adiabatic for saturated air, and towered vertically upwards till they reached an inversion at 7700 feet. The photograph reproduced in Fig. 12 was taken two or three minutes after that in Fig. 11, and shows the tops of the cumuli broken away. They soon dissolved away altogether, as is seen in Fig. 13 taken a few minutes later, from rather higher up and from a slightly different position. Other detached fragments may be seen at a distance in the background. The tops of narrow columns of cloud of this sort nearly always break away and dissolve, whether or not they reach an inversion. Near the coast they are most often seen in late summer or autumn, when the sea is warm, but inland they may occasionally be observed as early as April. It requires a very much broader column to produce a shower. The photographs show the edge of a layer of strato-cumulus which had moved east, at about 7000 to 7700 feet just under the inversion. Later in the day most of the cumuli grew up to the inversion, and as a result there was a good deal of strato-cumulus cloud inland, though as usual the level of the base of the clouds increased. The inversion amounted to 8° during the ascent, but during the descent half an hour later it only amounted to 3°, the temperature having fallen at 8000 feet, just above the inversion.

On the following page are given the upper air data for the dates corresponding to Figs. 8 to 14, and Fig. 6.

The humidities in italics refer to the hygrograph readings. On September 13 the temperature was 27° at 7500 feet, and on September 27 it was 25° at 7700 feet.

The upper winds were observed by pilot balloons at Montreuil or by anti-aircraft shells near Berck, except those on September 15 and 26 when there were no observations above 2000 feet available except far inland. On the evening of the 26th the low clouds over the Channel were arranged in waves nearly two miles in width, as shown in Fig. 10. The low clouds were between 3000 and 3800 feet, and were accompanied by very little turbulence, which accounts for their smooth appearance; the lapse-rate of temperature within and just under the clouds was of a stable type. The banks were roughly from south-west to north-east, very nearly along the wind current at their level, though not quite along it. The waves had a very slow lateral motion towards the south-east. Note the coast-line through the nearest gap, and also the small ripples across the cloud strips. The upper wind observation fifty miles inland two hours previously showed a Westerly current at 4000 feet and upwards, above the South-west current. The waves of Fig. 10 may have been set up by a West wind crossing a South-west wind. Half an hour later the wave clouds were replaced by a continuous sheet. There were other clouds above in a succession of thin layers near together from 6000 to 12,000 feet. There was a gradual inversion of 3° at about 7000 feet, but nevertheless there was rain during the night, which amounted to 7 mm. at Calais, and 4 mm. at Montreuil. The temperature may have fallen somewhat at 10,000 feet by the time

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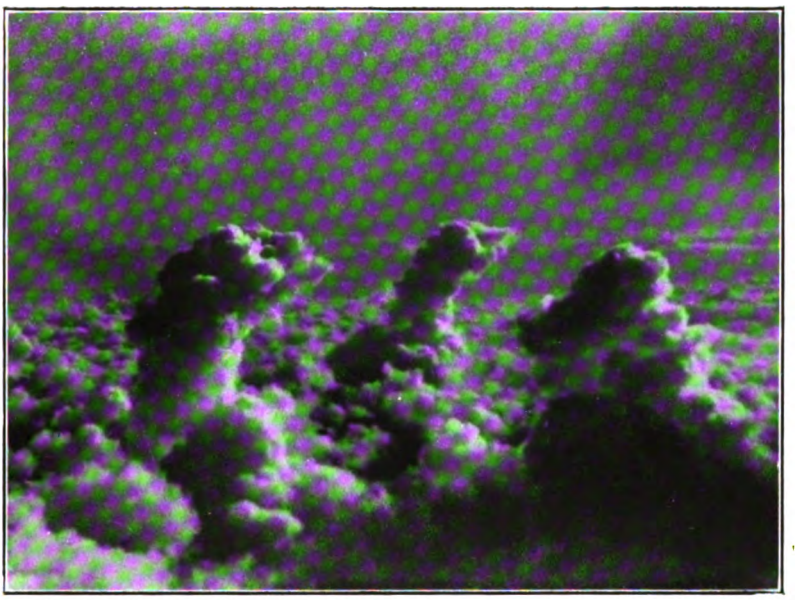

FIG. 11.—September 27, 1918, 7 h. Towering cumuli up to 7700 feet. Lower clouds about 1500 feet.

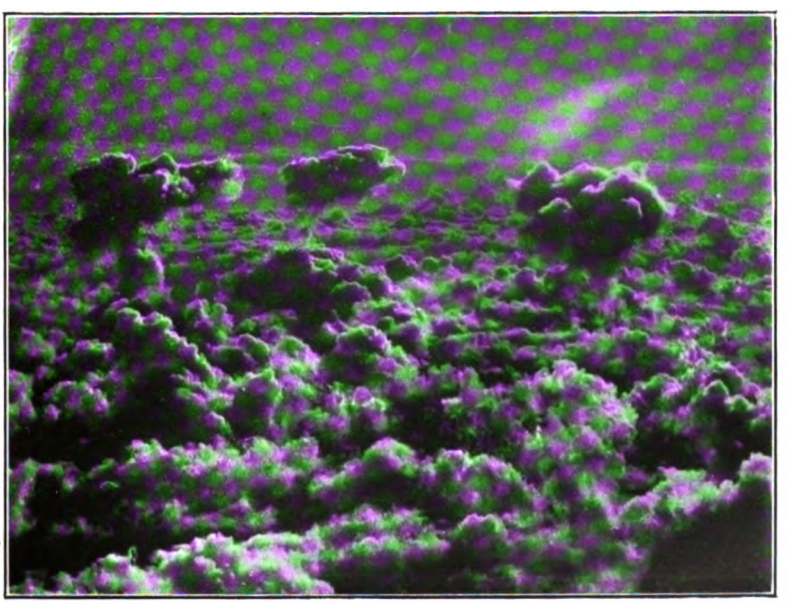

FIG. 12.—The tops of the same cumuli broken away, a few minutes later.

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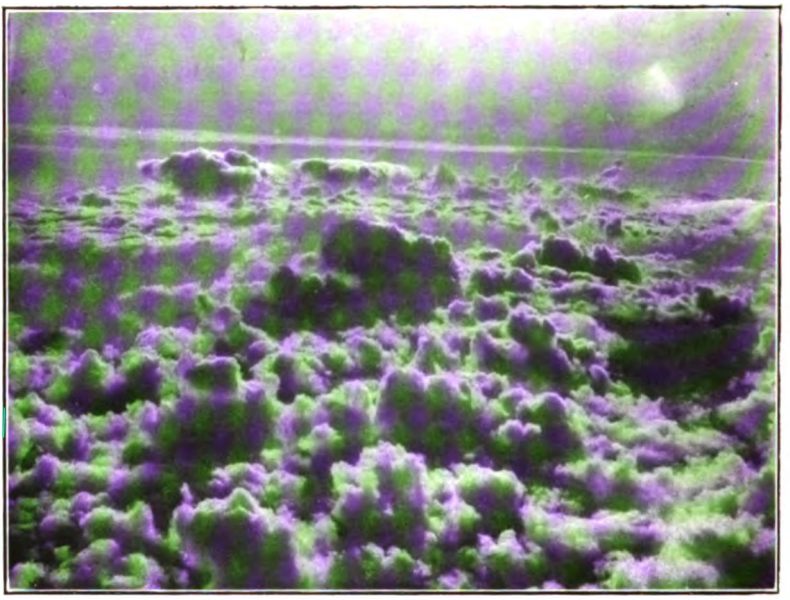

FIG. 13.—The same clouds as those of Fig. 12, dissolving away a few minutes later. Note other detached fragments in the distance, and the edge of a distant strato-cumulus sheet at 7700 feet.

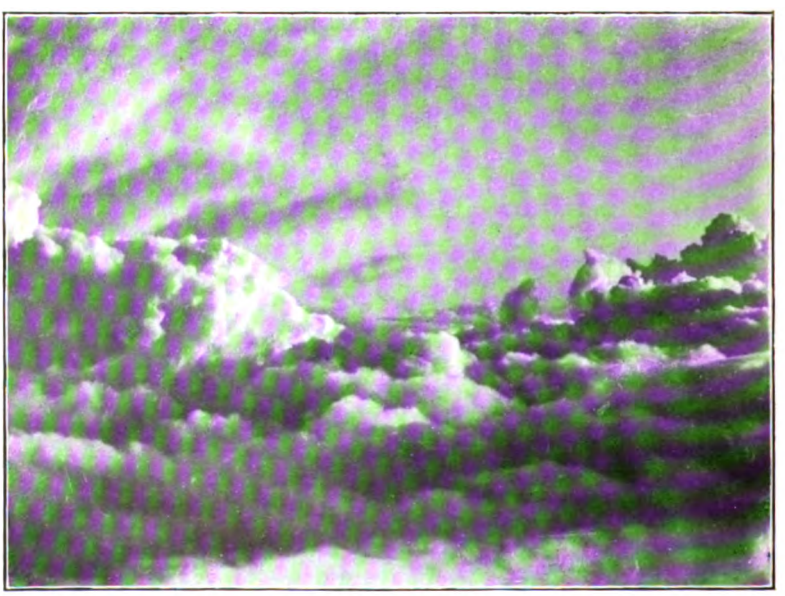

FIG. 14.—September 5, 1918, 18 h. The edge of a thunderstorm beyond the left of the picture, with clouds underneath and false cirrus on top left-hand corner. Top of the large cumulus on the right at 14,000 feet. Taken from 10,000 feet.

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the rain set in, but it cannot have fallen very much. Even if the lapse-rate of temperature is below the adiabatic for saturated air, it is possible for steady rain to fall if a thick saturated layer ascends on a gradual slope in the manner indicated by Bjerknes.[1] It will be noted that colder air had arrived next morning, behind a trough of low pressure.

Date and Time.	Height (feet).	0.	1,000.	2,000.	4,000.	6,000.	8,000.	10,000.	12,000.	14,000.
1918.										
Sept. 5, 18 hr.	Temp. ° F.	...	66	62	53	45	40	32	25	18
	R.H. %	...	66	66	76	74	72	64	*75*	*75*
	Wind Dir.	Calm	WNW	WSW	SW by W	WSW	W by S	WSW	WSW	...
	,, Vel. (m.p.h.)	...	4	7	12	28	26	21	26	...
Sept. 13, 9 hr.	Temp. ° F.	58	53	49	40	34	30	24	17	...
	R.H. %	76	88	69	94	87	93	73	*32*	...
	Wind Dir.	WNW	NW by W	WNW	WNW	W by N	W by N	W by N	...	...
	,, Vel. (m.p.h.)	8	18	19	30	31	36	38	...	...
Sept. 15, 10 hr.	Temp. ° F.	62	56	58	50	48	46	38	32*	...
	R.H. %	88	100	86	95	62	32	46	73*	...
	Wind Dir.	SE	S by W	SW by S	SSW	SW by W	WSW	WSW	W by S	...
	,, Vel. (m.p.h.)	4	12	18	19	23	28	26	28	...
Sept. 24, 7 hr.	Temp. ° F.	53	49	45	38	35	31	24	17	...
	R.H. %	86	88	81	81	47	40	*35*	*26*	...
	Wind Dir.	Calm	WNW	WNW	NW by W	NNW	NW by N	...	...	...
	,, Vel. (m.p.h.)	...	8	14	21	15	12	...	...	...
Sept. 26, 18 hr.	Temp. ° F.	59	55	51	47	40	41	36	30*	...
	R.H. %	71	74	66	100	100	94	93	93*	...
	Wind Dir.	...	SW by W	SW by W	W by N	W by S	WNW	WSW	W	...
	,, Vel. (m.p.h.)	...	18	21	30	41	43	34	34	...
Sept. 27, 8 hr.	Temp. ° F. (up)	55	51	46	40	30	33	28	20	...
	,, (down)	56	51	46	39	30	27	27	20	...
	R.H. % (up)	93	89	94	75	92	40	*20*	*12*	...
	Wind Dir.	NW by W	NW by W	NW by W	WNW	W by N	...	W by N	...	...
	,, Vel. (m.p.h.)	8	20	18	24	39†	...	45†	...	...

* Refers to 11,500 feet. † From shell-bursts.

The last illustration of the series shows thunder-clouds viewed from about 10,000 feet. The large cumulus on the left was joined to a thunderstorm, and the false cirrus seen in the left-hand top corner was at the edge of the "anvil" whose top exceeded 20,000 feet. The top of the cumulus on the right was at about 14,000 feet, and in the distance in the middle of the picture the false cirrus of another thunderstorm

[1] J. Bjerknes. "The structure of moving cylones." *Washington, D.C., U.S. Dept. Agric., Monthly Weath. Rev.*, **47**, 1919, pp. 95-99.

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may be observed, perhaps 100 miles away. The base of the clouds was at about 4000 feet, rather lower in places. The sharply defined clouds, of which an example is seen on the right of the photograph, consist of water-drops, which may be much super-cooled. On the other hand, the false cirrus consists of ice-crystals or snow-flakes which are usually developed from the water-drops, but may continue to ascend. The "anvils" on the tops of severe thunderstorms on hot summer days commonly reach the cirrus level, and the towering clouds with sharply defined tops consisting of super-cooled water-drops may exceed 20,000 feet before false cirrus forms. Even slight thunderstorms in cool weather, or heavy showers at any season of the year, may develop "anvils" up to or above 20,000 feet. In order that a thunderstorm of any intensity may develop, there must in the first place be enough moisture in the lower air for clouds to form as the result of the initial upward movement, which may either be a powerful convection current or a gradual lifting of the strata by converging currents of different temperature at the surface. In the second place, there must be a lapse-rate of temperature for rather more than 10,000 feet above the clouds which averages greater than the adiabatic for saturated air, with no inversion, and no nearly isothermal layer of greater thickness than a few hundred feet. Slight thunder is occasionally noted (as we have seen in the case of August 28, 1918), with an inversion at about 11,000 feet. The clouds probably reached 13,000 or 14,000 feet, as the tops of clouds are frequently observed to be considerably colder than the air surrounding them.

On the evening of September 5, 1918, there were several other thunderstorms visible in France and England besides the one whose boundary is seen in Fig. 14. A thunderstorm 100 miles away is a conspicuous object from the air, and the tops of "anvils" may sometimes be seen from 10,000 feet at a distance of about 200 miles. Thunderstorms can nearly always be avoided without difficulty by aeroplane pilots engaged in ordinary peace-time flying. The higher the pilot flies the more conspicuous the tops of the thunder-clouds become, and the more easily can they be avoided. Sometimes there are extensive clouds at about the level of the base of the thunder-clouds, and it is necessary to climb above them in order to see the thunderstorms at a distance, and to judge the best course to fly in order to avoid them.

The results obtained at Berck illustrate the value of the aeroplane as an instrument for meteorological research. In addition to the photographs, a large number of observations of clouds and visibility were made, showing their relations to the upper air conditions and the general meteorological situation. There were 550 ascents up to at least 10,000 feet, most of them up to 14,000 feet. Meteorological research by means of aeroplanes can be carried out more effectively by a pilot than by an observer going up as a passenger. A pilot who specialises in the work can fly up through any thickness of cloud, while a pilot without experience in cloud-flying is liable to get into difficulties if he attempts to do so.

The photographs only show a small sector of the clouds and convey little impression of the grandeur of the view all round. Very fine cloud scenery may often be seen from within a couple of miles of the ground. As civil aviation develops and becomes cheaper, increasing opportunities of viewing this cloud scenery will present themselves.

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DESCRIPTION OF THE NIGHT-SKY RECORDER, RECENTLY BROUGHT INTO USE AT THE ROYAL OBSERVATORY, GREENWICH.

THE object of this instrument is to supplement the daily sunshine record in so far as it gives an indication of the amount of cloud.

It consists of a small camera in a fixed position pointing to the Pole of the heavens. The lens is a single component of a doublet, and is of 8-inch focal length and 0·4-inch aperture, thus working at $f/20$. It is found that this aperture in conjunction with plates of "ordinary" speed will give a good record even at full moon. Quarter plates are used and up to the present only the trails of Polaris and δ Ursae Minoris have been measured. The time of exposure is that during which the sun remains at more than about 10 degrees below the horizon. In practice, the times of opening and closing the exposing cap are not changed oftener than once a week. On very fine nights the 21-hour observer may make a break in the record, to check the meridian setting. Protection from rain is afforded by enclosing the camera in a larger box, about twice the length of the camera, extending about nine inches beyond the lens, which is further protected by a hood. This is found to be a perfectly adequate protection from dew and light rain showers. The only risk is that of drifting snow or driving rain from the north. The plates are developed uniformly, using a rapid reagent, and drying has also to be hastened in order to enable the dry negative to be measured in time for the morning report.

Measurement is made by means of a photographic scale consisting of concentric circles, divided by a time scale, whose radii are slightly greater than those of the trails of Polaris and δ Ursae Minoris. The photograph is placed in contact, film to film, with the scale and the trails made concentric with the scale by means of adjusting eccentrics in the measuring frame. The registered trails of the two stars are then read off to minutes, and the respective percentages of the whole time of exposure are included in the daily telephone report to the Meteorological Office.

DISCUSSION.

Sir NAPIER SHAW said the night-watchman was very much on his mind. He wondered whether the Royal Observatory was prepared to supply a portable automatic one.

Mr. W. W. BRYANT said they proposed to have an alarm clock and also to introduce a number of improvements later.

Sir NAPIER SHAW said he would like to thank the Royal Observatory for having brought this recorder into operation. It was astonishing that means of measuring the sky at night had not been introduced before. It was done at Blue Hill but at very few other observatories. The variation in the cloudiness of the sky at night was even more interesting than the record of sunshine in the day, because in the day cloudiness was interfered with or intensified by the effects of solarisation, whereas at night the effects were more generally

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meteorological and probably of more easy dynamical investigation than the records of sunshine.

Mr. J. S. DINES asked if some extra means for getting the zero of time were not required if there were clouds over the pole star when the camera was opened and closed.

Mr. W. W. BRYANT said the edge of the plate came in the same position every night and there was four minutes extra difference to be allowed, on each successive day, between sidereal and mean solar time.

Mr. F. J. BRODIE said that if the instrument did not begin to act until darkness had set in there was a part of the day from sunset to darkness for which there was no record.

Mr. F. J. W. WHIPPLE said that the night-sky recorder would have a great advantage over the sunshine recorder in that the pole star was always at the same height above the horizon. Curves drawn to represent the diurnal variation in the proportion of bright sunshine showed a maximum of sunshine in the middle of the day, but the suggestion that cloudiness was at the minimum at the same time was of course false. The record of the night-sky-recorder from 9 p.m. to 10 p.m. would be comparable with that from 12 p.m. to 1 a.m. and that would be an immense advantage in interpreting hourly values.

Mr. P. M. RYVES thought the focal length should be longer so as to give a more open scale, and an electric clock used for opening and shutting the camera.

Mr. J. S. TURNER asked if it would be possible to arrange a series of cameras in a cone shape so as to take a series of photographs of the first magnitude stars.

Mr. W. W. BRYANT said it was difficult to guarantee the setting of the camera unless it was pointed to the pole. It was very doubtful whether anything would be gained as a set-off against the greatly increased difficulties.

Meteorological Papers read before the Royal Society.

It has been represented to the Council of the Royal Meteorological Society that Fellows are put at a disadvantage in following the progress of their science owing to the fact that a considerable proportion of the meteorological papers of greatest interest are submitted to the Royal Society and are published in the *Proceedings* of that body so that they do not come into the hands of the Fellows of the Royal Meteorological Society as such. Whilst appreciating the advantages of a system which keeps investigators in different branches of science in touch with each other, the Council considers that some machinery for circulating meteorological papers amongst those who are directly interested is desirable.

It has been ascertained that reprints of the papers can be obtained from the Royal Society on satisfactory terms, and it is suggested that a list of Fellows who would like to receive these should be prepared, such Fellows paying a subscription in advance to cover the cost. As the number of papers to be circulated would vary from year to year the subscription would be regarded as a deposit, a notice being sent to Fellows when it was exhausted. It appears that the number of papers from the *Proceedings* of the Royal Society would be about four each year and the cost would be about one shilling each. A deposit of ten shillings is suggested in the first instance.

Fellows who wish to support the scheme should communicate with the Assistant Secretary.

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LOCAL WEATHER CONDITIONS AT MULLION, CORNWALL.

By Lieut. N. L. SILVESTER, R.N.V.R., F.R.Met.Soc.

[Received April 9, 1919—Read April 21, 1920.]

General.

As most of the local peculiarities of weather in the vicinity of Mullion are directly or indirectly connected with local orographic features, it will be necessary briefly to describe these features.

The Air Station is situated near the summit of the peninsula known as the Lizard and Meneage at a point on the western boundary of the uninhabited scantily-clad tract of moorland of Goonhilly Downs. The plateau surrounding the Station has an average height of about 250 feet rising to a maximum of 370 feet at Dry Tree, about a mile east of the sheds where the new Meteorological Observatory is situated. The ground on which the main body of the Station is built has an average altitude of 300 feet above M.S.L.

On every side but the north-west and west the plateau stretches in uniform fashion for miles, with few undulations until close to the coast line, where it is intersected by steep and narrow valleys, usually well wooded, by which the surface drainage escapes precipitately to the sea.

The peninsula is bounded on all sides except the north by the sea. On that side the submerged river valley of the Helford divides the Lizard plateau from the main Cornish peninsula. A few miles to the north of this inlet rises the main watershed of Cornwall, lying south-west to north-east, in this part attaining a height of 800 feet only.

The sea bordering this peninsula to the west is a part of Mounts Bay, well known to sailors for its violent squalls. The intensity of squalls in this bay is attributable to the shape and position of the granitic boss of Land's End, which must cause some dividing and eddy motion in strong W and NW winds, during which squalls are most prevalent.

With the exception of a few superficial gravels of recent origin on Crousa Common, 5 miles to the east of the Station, the whole district is composed of rocks quite impermeable to water, and which as a rule disintegrate into very retentive clays. Consequently the rainfall has but two means of escaping from the surface—

(1) by drainage along the surface,
(2) by evaporation into the air.

Thus in spite of the height of the plateau above mean sea level, the greater part is covered by a very wet soil—the rain water standing about in stagnant pools on the surface, or forming with the coarse vegetation shallow swamps that do not dry up during the most persistent drought of summer. From above in the winter the downs to the east of the Station resemble a shallow lake that is becoming filled up and overgrown by aquatic plants.

The soil on the summit of this plateau is in fact too wet to be of any use to farmers—all the farm land being situated in the narrow valleys or on ground with such a decided slope as to prevent the rain water from standing where it falls. This last feature has a well-marked influence on

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the humidity of the air at the surface and consequently on the formation of radiation fog in the absence of a pressure gradient.

It has been noticed on more than one occasion that when conditions have favoured the formation of radiation fog, this fog has formed around Dry Tree some time before it has formed near the Airshed, and that it was thicker and denser there. As the hut is situated on the summit of a slight hill standing 70 feet above the level of the rest of the Station, the natural tendency in such a case would be for the cold air as soon as formed to flow away. This fact therefore tends to support the theory that the wet state of the moor round Dry Tree does influence the atmospheric humidity near the surface.

The proximity of the sea, which is but 3 miles distant from the Station on the west-south-west and south-south-east and not more than 6 miles distant in any direction except to the northward, has the most marked influence in modifying general weather conditions. This in conjunction with the abrupt coast line, only broken in a few points by very narrow valleys, is the cause of an abnormal amount of thick weather of the nature of coast mists at all seasons, supplemented by sea fogs in late spring and early summer, and by radiation fogs in late summer and in autumn.

With the exception of plantations on the hill sides to the south-west of the Station that bound the landing ground on the west, and several large detached plantations a mile and more to the north of the Station, the adjacent country is not well wooded, although climatic conditions favour the rapid growth of vegetation. This is much in evidence in the dense undergrowth of the hedgerows which in many places have been allowed to attain a height of from 10 to 20 feet and a width of from 5 to 30 feet forming excellent screens from strong winds, and the characteristic driving mists, to travellers on the highways. Where these thick hedges are not in use as boundaries high stone walls divide the fields and shelter the roadways.

The photograph (Fig. 1, p. 248) taken near the weather hut at Dry Tree, gives a very fair idea of the exposure and of the nature of the immediate vicinity. Unfortunately at the time when this was taken the visibility was not as good as it might have been, so that the distant horizon including the western side of Mounts Bay, with the hilly peninsula of Land's End and the line of hills to the north, does not appear.

That the immediate vicinity of Dry Tree is favourable to the formation of vertical currents in the atmosphere is proved by the complaints of aeroplane pilots who have frequently reported very bumpy flights over the moors close to the weather hut. I have accompanied these pilots when opportunity occurred and can confirm these reports. On one occasion I felt the aeroplane come under the influence of two distinct downward currents in rapid succession, but on most occasions a downward current has been always preceded or followed by an upward current of similar velocity. The contour of the surface here cannot be the cause of these currents. The true cause I believe to be the relative wetness of the land. In some places the surface drainage lies about in large shallow pools, whilst in other places the vegetation is thicker and the rain water becomes more or less absorbed in the soil and roots and makes a spongy morass.

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I have noticed from the movements of pilot balloons in the first half-minute of their ascent that strong up-currents are often present on a sunny day on the lee side of a thick hedge when exposed to the full heat of the sun. It is this fact that accounts for such small ratios between surface and gradient winds for N winds at midday, *i.e.* 0·5, 0·8, 0·9.

It has been proved fairly conclusively that ground-swells which reach this coast in calm weather form useful indications of windy weather; often giving as much as 24 hours warning.

The direction from which these swells approach gives a fair indication of the direction from which the wind will blow.

These ground-swells on calm nights are audible as far as 3 miles inland and sound at that distance very similar to a heavy train crossing a viaduct.

The damping effect of the Cornish peninsula on the velocity of cross winds, caused by friction over a very uneven surface, is clearly proved by reports of pilots who have reported, when crossing from one side to the other, a strong steady current to windward, becoming bumpy over the land, and quite a light wind to leeward when within a few miles of land; but, on proceeding further to sea to leeward, have again encountered a strong current equal in velocity to that to windward.

TABLE I.—Analysis of Anemobiagrams (Halliwell-Dines Anemobiagraph) for selected Days.

	Old Site. August 1916 to January 1917. Means.							New Site. April 1917 to October 1917. Means.						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wind Direction.	Maximum Gust.	Diurnal Range of Mean Velocity.	Direction Fluctuation in Degrees.		Maximum Range of Gustiness.	Column 6 expressed as Percentage of Column 2.	Number of Cases.	Maximum Gust.	Diurnal Range of Mean Velocity.	Direction Fluctuation in Degrees.		Maximum Range of Gustiness.	Column 13 expressed as Percentage of Column 9.	Number of Cases.
	m.p.h.	m.p.h.	Night.	Day.	m.p.h.			m.p.h.	m.p.h.	Night.	ay.	m.p.h.		
N	25	11	40	90	13	52	13	27	18	15	70	14	52	23
NE	21	10	65	115	12	57	14	16	8	7	100	9	56	3
E	22	7	140	185	14	64	6	25	13	15	55	10	40	22
SE	37	11	50	70	14	38	6	25	16	35	70	9	36	2
S	37	13	30	65	16	43	5	24	10	20	65	10	42	15
SW	29	6	75	95	15	52	22	31	12	20	50	14	45	21
W	31	11	70	100	18	58	24	30	13	15	60	13	43	39
NW	33	16	30	85	18	55	15	30	18	20	80	15	50	13

The days selected were those when the wind direction was approximately constant and the velocity exceeded 10 m.p.h. in gusts.

"Range of gustiness" is the difference between the wind velocity in a gust and that in the lull immediately preceding or subsequent to that gust. "Direction fluctuation" is measured by the number of degrees through which the anemometer vane rotates between two consecutive gusts.

It must be mentioned that the two main sections of Table I. are not strictly comparable, as the periods under investigation covered different seasons of the year. The shortness of the period in the case of the

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old site is regrettable, but quite unavoidable, the anemometer not being erected there until August 1916, and being dismantled and transferred to the new site at Dry Tree between January and April 1917.

The above analysis was undertaken, in the first place, solely in the interests of pilots of lighter-than-air craft. This necessitated a form of analysis, much of which will be considered heterodox by the meteorologist. One of the most difficult problems in airship navigation is the handling of the ship on the ground. The difficulties increase in proportion to the square of the velocity of the wind; and it is the maximum gust that has to be considered rather than the mean velocity. The difficulty is further aggravated by the eddy motion in the air near the surface. This motion is divisible into two components:—

(1) The longitudinal component which appears in the anemometric

FIG. 1.—View of the immediate vicinity of the weather hut at Dry Tree.

analysis of pressure-tube records as alternating gusts and lulls. Some measure of this appears under the heading of Maximum Range of Gustiness (*vide* columns 6, 7, 13, 14).

There is sometimes ambiguity in the use of the expressions "gustiness" and "squalliness." In this paper the following distinction has been observed:

"Gustiness" is a fluctuation in wind velocity of considerable regularity with a period not exceeding five minutes. "Squalliness" is a fluctuation with a period of at least ten minutes and characterised by its irregularity in period and amplitude.

"Unsteady direction" may be defined as an irregular oscillation in the mean direction of the wind, having a minimum period of ten minutes.

Eddy motion as represented by the values in columns 4 and 5 and 11 and 12 shows a marked minimum at night for all directions. The

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effect of the better exposure is to accentuate this contrast between day and night. A comparison of the two sites brings out a marked decrease in direction fluctuation for all directions at the new site with the two exceptions of S and SE winds during the day. These two directions were the best exposures on the old site.

A comparison of columns 7 and 14 demonstrates the local effect of the Airshed on the wind at the old site; there being maximum values for the directions NE and E (in which directions the shed lay). These maxima disappear on the new site. Column 14 points to a minimum gustiness for winds with a Southerly component, and a maximum in those with a Northerly component.

Column 10 giving the mean diurnal range corroborates the truth of the quaint old proverb "The North wind goes to bed at night." Little more can be deduced from this and column 3 because so many cases were analysed where the diurnal range was masked by changes of velocity due to modifications of the barometric gradient.

TABLE II.—Characteristics of the Surface Winds not included in Table I., and Sundry Inferences.

Old Site.	New Site.
Northerly Winds.	
8 cases squally and in 5 of these the direction was unsteady.	14 cases squally and in 11 of these the direction was unsteady.
1 case of steady velocity when the maximum was 15 m.p.h.	1 case of steady velocity when the maximum was 15 m.p.h.
Northeasterly Winds.	
4 cases squally.	The number of cases is insufficient.
3 cases of unsteady direction.	3 cases of unsteady direction.
3 cases of steady velocity.	Notice the very considerable reduction in direction fluctuation (especially during the night) as compared with the old site.
3 cases of unsteady velocity.	
The influence of the airshed which stood directly to windward at a distance of about 100 yards is shown by the direction fluctuation which, when the wind was ENE, varied between 150° and 360° as compared with 0°–60° when the wind was NE by N and had a free course parallel to the length of the shed.	
Easterly Winds.	
3 cases squally.	3 cases of a tendency to squalliness.
Here again the interference of the airshed and windscreens is shown. While the wind was E by S the hut was just clear of eddies caused by the windscreen. Accordingly the direction fluctuation remained at about 45°. Immediately the wind backed E by N this quantity increased to between 130° and 360°.	9 cases of unsteady direction.
	The direction fluctuation rarely exceeded 45° when the velocity exceeded 20 m.p.h. It would therefore be easier to land an airship in a strong E wind than in a N wind of equal strength.
	In 5 cases the wind veered during the forenoon, and backed to its original direction after noon.
	Range of gustiness is small.
Southeasterly Winds.	
These winds are steady both in direction and velocity.	Number of cases insufficient.
Small direction fluctuation as compared with E winds on this site.	
Minimum range of gustiness.	

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TABLE II. (*continued*).

Old Site.	New Site.
Southerly Winds.	
Number of cases insufficient. No squally winds. Minimum direction fluctuation. The interference of the wood to the SSW and S is shown, as the direction fluctuation increased to 120° when the wind veered into those directions.	3 cases squally. 4 cases where the diurnal range is masked by change in pressure gradient. In all other cases the diurnal range is considerable. 8 cases of unsteady direction. (This feature would not affect the handling of airships on the ground, as the changes are slow.) Minimum range of gustiness.
Southwesterly Winds.	
6 cases squally. 14 cases where the diurnal range is masked. 2 peculiar cases where the diurnal increase is quite inverted; the minimum velocity occurring during the day. In this direction the surface wind is considerably affected by a large wood that approaches to within 100 yards of the hut. This is evident by— (1) The large range of gustiness with strong winds. (2) Direction fluctuation which is large during the day with little decrease at night. Were this obstruction removed the winds would be steady.	10 cases squally. 8 cases where the diurnal range is masked. In all other cases it is large. 4 cases of wind { backing in the forenoon. / veering in the afternoon. (Cf. E winds.) The advantage of this exposure is clearly seen from the small degree of direction fluctuation.

This direction is rather dangerous for handling airships on the ground, but the more exposed situation is preferable, although for the same gradient the wind would be stronger near the surface.

Westerly Winds.	
Squalls common. 16 cases. 1 case only of steady velocity. 6 cases of unsteady direction (these were all squally). 9 cases where the diurnal range is masked. 2 cases of inverted diurnal range. In the remaining cases it is large. Direction fluctuation is large. The time of maximum velocity is very variable.	Squalls common. 21 cases. 30 cases of unsteady direction. 13 cases where the diurnal range is masked. In the remainder, the range is very great. Range of gustiness compares favourably with that on the old site. Note the smaller direction fluctuation on this site. 5 cases of wind { veering in forenoon. / backing in afternoon. 3 cases of wind { backing in forenoon. / veering in afternoon.

It is very dangerous to handle airships on the ground in strong winds from this direction, but full exposure to the wind uninterrupted by any obstacles is preferable to partial shelter as of windscreens. Nevertheless these winds possess advantages for long patrols in which ships can be handled before sunrise and after sunset, when the velocity will be insignificant compared with its midday value.

Northwesterly Winds.	
8 cases squally. 6 cases of unsteady direction, all of which were also squally. 5 cases where the diurnal range is masked. In the remainder it was exceptionally great. Range of gustiness is large. Direction fluctuation shows a marked minimum at night.	9 cases squally. 11 cases of unsteady direction, 9 of which were also squally. 1 case where the diurnal range is masked. In the remainder it is exceptionally great. Range of gustiness is large but less than that on the old site. Direction fluctuation shows a marked minimum at night.

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TABLE II. (*continued*).

Old Site.	New Site.
Northwesterly Winds (*continued*).	
1 case of wind { veering in forenoon. backing in afternoon.	2 cases of wind { veering in forenoon. backing in afternoon.
	Maximum velocities occur between the usual hours (11 to 16 h.).
	1 case of dangerously sudden increase in velocity from 4 to 50 m.p.h.

This direction is also dangerous for handling airships on the ground, but good for long patrols commencing at dawn and finishing at dusk. In this way most of the squally winds can be avoided. There is a slight advantage in having a good flat space of ground for the handling of ships in these winds.

TABLE III.—Relation between Surface and Gradient Winds.

N.B.—The wind at 1500 feet is assumed to be the gradient wind. Pilot balloons observed with 1 Theodolite.

From ascents at Dry Tree, April 1917–October 1917.

Direction.	*Ratio Gradient/Surface.*			*Number of Ascents.*			
	Mean Morning.	Mean Midday.	Mean Evening.	Morning.	Midday.	Evening.	
N	2·2	1·1	1·2	15	16	20	
NE	2·5	1·2	2·2	9	3	4	
E	1·9	1·2	1·8	5	13	8	
SE	1·7	1·4	1·5	5	3	4	
S	1·45	1·3	1·2	4	8	4	
SW	1·9	1·15	1·4	14	12	8	
W	2·1	1·2	1·2	19	31	27	
NW	2·0	1·2	1·3	14	13	18	
Mean of all directions.	2·03	1·20	1·48				

Mean of all ratios = 1·55.

From ascents at Old Site near Wardroom, August 1916–January 1917.

							Obstructions to surface winds.
N	3·3	3·1	2·4	7	3	4	Wardroom, Sick-bay, Power House.
NE	2·9	2·1	2·9	10	9	4	Airshed and windscreens.
E	1·9	1·5	2·0	4	1	1	
SE	1·6	1·6	1·0	5	2	1	
S	1·8	...	...	5	0	0	
SW	2·8	2·4	2·5	8	10	7	Wood ½ mile to 300 yards thick.
W	2·2	2·3	1·8	8	11	4	
NW	3·2	1·7	2·3	14	9	8	Valley 60 ft. deep, 500 ft. wide.
Mean of all directions.	2·95	2·15	2·34				

Mean of all ratios = 2·55.

N.B.—Following cases omitted in computing above tables:
(*a*) When surface wind was 2 m.p.h. or under.
(*b*) When a reversal or unusual change in direction was shown by pilot balloon.

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A glance at the two sections of the above tables will be sufficient to show the advantages of the new site of the weather hut at Dry Tree over the old site near the wardroom where there was only one really good exposure to the south-east, where the wind had an uninterrupted flow over the Goonhilly Downs and the landing ground before reaching the hut.

For four directions, the ordinary increase of surface wind relative to the gradient wind is shown at midday.

The first exception (Northerly winds) shows that there is no decrease in the evening corresponding to the increase at midday. This can be explained by reference to the local contour. To the north there lies a range of hills 700–800 ft. high. The majority of the ascents from which these ratios are computed occurred during fine days. The cooling effect of the surface layers towards sunset, which on level ground would cause the usual decrease in surface wind, was the cause of an increase in velocity due to the relatively dense air flowing down the southern slopes of these hills. We thus have the proof in the above figures of a local katabatic component for Northerly winds.

The next exception is Southerly winds. In this case there are not a sufficient number of ascents to deduce anything from these ratios. The last two exceptions, W and NW winds, show the same peculiarity as the N winds, *i.e.*

no decrease in surface winds in evening (W winds),
little „ „ „ „ „ (NW „).

The only explanation is that winds from these directions are often squally and at such times vertical currents exist. The morning balloons were often sent up before the wind became squally, whilst at the time of most of the evening ascents the wind on the surface had not become steady. Assuming these facts it means that we have to call the evening ascents unreliable owing to the presence of vertical currents.

For a period of about four weeks subsequent to 15th September 1917, the very small range of gustiness for winds from all directions and at all velocities is apparent from the anemograms. This was first attributed to some internal friction in the anemobiagraph; but there is no evidence of this except that on one night both meteorological officers considered that there had been a considerably greater velocity of wind than was registered. It is quite possible that this may be a partly seasonal and partly local characteristic. It would be interesting to discover if a similar characteristic was noticeable at adjacent stations, Scilly, and Pembroke.

On the 16th June 1917 between 14.00 and 15.00 G.M.T. two small whirlwinds were observed to pass the weather hut. Both approached from the east, travelling in a straight line with a velocity of about 20 m.p.h. The vertical and upward motion of the air in the first of these was very apparent as the centre passed over the writer, lifting and twisting his jacket. The diameter as shown by movement in the grass and hedges was little more than 10 feet at the surface. A thunderstorm appeared in the east within an hour of these miniature disturbances.

Fog and Mist.

For the purpose of investigating local peculiarities in the formation of mist and fog it is necessary to classify all such occurrences under at least three headings, according to the cause of their formation.

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The subdivisions used are (1) Radiation fog.
(2) Sea fog.
(3) Coast mist and drizzle.

What appear to be two distinct phenomena are quite inseparable at Mullion, as a true coast mist, that can be obviously seen to be nothing

TABLE IVa.—Radiation Fog.

Date.	Time.		Duration.	Surface Wind.		Remarks.
	From	To		Direction.	Velocity.	
1916.	h.	h.	hrs.		m.p.h.	
23/24 July	18	9	15	E-SE	2-4	
24/25 ,,	18	6	12	W	2-3	
22 Aug.	0	9	9	Calm-ESE	0-8	
5/6 Sept.	21	9	12	Calm	0	
10 ,,	0	9	9	NNE	4-6	
16/17 ,,	21	7	10	N-W	2-6	
3 Dec.	0	11	11	Calm-NE	0-8	
6 ,,	18	19	1	Calm	0	
7 ,,	8	10	3	Calm	0	
11 ,,	5	11	4	Calm	0	
12 ,,	4	8	5	Calm	0	
1917.						
7 Jan.	7	9	3	Calm	0	
18 Feb.	0	5	5	Calm	0	
18/19 Feb.	19	6	12	Calm	0	
13 March	0	6	6	W	5	
24 April	2	9	7	Calm	0	
30 Ap./1 May	20	5	10	N-NNE	19-8	Fog drifting from inland.
2 May	5	9	5	NE	7-14	
2/3 ,,	22	4	7	NE	9-13	
4/5 ,,	21	3	7	NNE	4-5	
8 ,,	0	7	7	N-E	7-0	
8 ,,	20	24	5	Calm	0	
19/20 May	20	6	10	Calm-NE	7	
10/11 June	19	2	8	NE-Calm	10-0	
11/12 ,,	22	5	8	NE-NW-Calm	8-0	Temporary improvement, 24 h.
13 ,,	2	3	1	WSW	10	
14 ,,	2	3	2	W	7-8	
15/16 ,,	23	8	10	Calm	0	
14 July	3	5	3	W-NW	4-6	
20/21 July	24	5	6	Calm	0	
21 July	20	...	1	Calm	0	
5 Aug.	20	...	1	Calm	0	
6 ,,	21	23	3	W	5	
20 ,,	2	5	4	WSW	4-6	
23 Sept.	23	6	8	SE	3	
28/29 Sept.	21	3	7	Calm	0	
29 ,,	20	23	4	Calm	0	
3 Oct.	4	6	3	W	6-7	

more, often grows wet enough to be called drizzling rain, whilst on the approach of many depressions the very fine driving mist that accompanies the fall of pressure can equally be termed a coast mist unless it can be proved by simultaneous observations at sea that it exists there also.

There is also on some occasions a similar difficulty in discriminating between coast mists and sea fogs.

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Radiation fogs occur at all times in the year but are more frequent during the summer months. They are only liable to form when the wind on the surface is under 10 m.p.h. and may be expected more frequently with light winds from the NE than from other points of the compass, as it is in this direction only that land of any considerable area is to be found.

TABLE IVB.—SEA FOG.

Date.	Time.		Duration.	Surface Wind.		Remarks.
	From	To		Direction.	Velocity.	
1916.	h.	h.	hrs.		m.p.h.	
31 July/1 Aug.	21	12	15	NW	2-8	
2 Aug.	3	9	6	W	2	
5 ,,	21	24	3	Calm	0	
11 ,,	0	15	15	SSE	0-10	
24 Sept.	8	11	3	SSE	4-12	Did not affect station.
1917.						
9/10 May	0	9	33	E-S	4-26	Sea and coast fog.
10/11 ,,	18	12	18	S-E	4-17	
12/13 ,,	17	6	13	S	8-16	
13/15 ,,	15	7	40	SE-E-Indef.	20-4	Did not envelop station till 19h., when wind backed ENE. Enveloping station at night: keeping out at sea in day.
21/22½May	20	24	29	W-NW-N / Calm-SW-SE	0-22	Fog kept at sea during day. Disappeared with increasing wind.
15 June	9	12	4	SE	16-18	
16 ,,	6	15	10	Calm-NE	0-15	Retired to sea after sunrise.
3/4 July	17	9	17	Calm-W-NW	0-8	
11/12 July	21	5	9	SW-S	5-11	
22 ,,	15	18	4	E	12-15	Did not envelop station.
5/6 Aug.	23	16	18	Calm-Indef.	Calm-6	Retired to sea at 7 (6th) and remained there rest of day.
6/7 ,,	24	6	7	W	4	Disappeared at sunrise with increase of wind.
5 Sept.	8	14	7	S-SE	20-14	Drizzle.
13/15 Sept.	20	6	35	W	10-35	
15/16 ,,	15	19	25	SW-S	5-17	Intermittent.
17/18 ,,	9	16	32	SW-S	0-25	Drizzle.
19 ,,	12	17	6	Calm-NW	0-7	
23 ,,	6	15	10	Calm-S	0-9	
24 ,,	7	13	7	Calm-SE	0-5	Did not envelop station.
24/25 ,,	24	2	3	S-SSW	4-7	
29 Sep./2 Oct.	24	21	70	Calm to E'ly / Calm to SW'ly	0-12	
20/21 Oct.	24	9	10	S	20-25	Did not envelop station.

At Mullion this type of fog never persists long after sunrise and scarcely ever commences to form until after sunset. Many of these fogs escape observation, hidden in deep valleys around—that are mainly their cause—owing to the situation of the observatory, which although on the summit of the peninsula does not command a view into any of the valleys.

Sea fogs (Table IVB.), are entirely restricted to the summer months in this vicinity and are most frequent during the month of May.

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TABLE IVc.—Coast Mist and Drizzle.

Date.	Time.		Duration.	Surface Wind.		Remarks.
	From	To		Direction.	Velocity.	
1916.	h.	h.	hrs.		m.p.h.	
12 Aug. . .	6	9	3	SE	10-20	Coast mist only.
22 ,, . .	21	24	3	SE	6	,, ,,
23/25 Aug. .	20	12	40	SSW	2-22	
4 Sept. . .	9	15	6	SW-WNW	4-26	
11 ,, . .	12	18	6	SW-NW	12-14	No mist.
25 ,, . .	13	24	11	E-S	4-30	Coast mist only.
1/2 Oct. . .	12	11	23	SE-SW	5-35	
2/3 ,, . .	14	11	21	SW	6-23	
3/4 ,, . .	14	8	18	S-SW	8-30	
4/6 ,, . .	22	16	42	SW	10-42	
8 ,, . .	0	10	10	W	12-26	
9 ,, . .	0	7	7	SW	10-20	Coast mist only.
9/10 ,, . .	12	8	20	SW	7-20	
12/13,, . .	16	18	26	SW-W	9-23	
17 ,, . .	8	10	2	S	13-30	
10/13 Nov. .	3	9	78	S-W-Calm	0-28	
13/14 ,, .	20	15	19	Indef.-E	4-20	Mist intermittent 14th.
23/24 ,, .	22	12	14	SSW	39-14	Wind decreased as visibility increased.
25 ,, .	2	5	3	SSW-WSW	10-20	
28/29 Dec. .	16	10	18	SW	16-34	
29/30 ,, .	14	3	13	SW-W	7-38	
1917.						
30 Dec.–1 Jan.	23	7	32	SW-W	9-30	
1/2 Jan. . .	17	16	20	W	8-29	
3 ,, . .	10	11	2	WSW	14-24	
19/21 Feb. .	7	10	44	SE-SW-NW	8-27	
23/24 ,, .	14	9	17	S-W	28-5	
24 ,, .	10	13	4	N	5	Coast mist only, did not envelop station.
24/25 ,, .	16	4	13	W	8	Coast mist only.
25 ,, .	5	8	4	W	5-7	Coast mist only. Did not envelop station.
25 ,, .	12	15	4	W	20-24	
4 March . .	10	16	7	SE-S	Gale	Visibility increased when wind dropped.
9 ,, . .	3	8	6	SE-S	,,	
10 ,, . .	0	21	21	S-SW	24-40	Visibility improved when wind veered.
11/12 March .	13	8	19	NE-N	25-10	No mist.
28 ,, .	11	20	6	WSW-W	20-35	
19 April . .	20	22	3	NW	18-18	Clear on south coast.
26/27 April .	18	7	13	NW-N	9-12	Coast mist only.
3/4 May . .	19	3	9	E-NE	12-19	,, ,,
12 ,, . .	0	6	6	NE	13-19	,, ,,
15/16 May .	22	10	12	N-E	6-22	
16/17 ,, .	16	11	19	E	14-25	,, ,,
18/19 ,, .	0	10	34	E-S	35-8	
21 ,, .	0	15	15	N-W-SW	0-20	
25 ,, .	7	10	4	S	20-25	,, ,,
27 ,, .	0	6	6	W-NW	6-17	,, ,,
28 ,, .	18	20	3	N	20-25	
1 June . .	3	7	5	SW	25-35	
6/7 ,, . .	19	6	11	W-SW	4	
8 ,, . .	2	9	8	SW	15-18	
13 ,, . .	14	22	7	SW	20-30	
19/20 June .	16	12	21	S-Indef.	5-0	
27 ,, .	1	15	15	S-SW	16-31	

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In that month there is the greatest difference between air temperature over sea and land—the sea temperature being considerably lower than the land temperature. The positions and duration of these fogs are most difficult to forecast. The appearance of fog seaward from a leeshore is easily explained, but when one occurs to windward and then comes drifting inland not infrequently in the middle of a hot day, even explanation is almost impossible.

On one occasion this type of fog was encroaching on the station from the west, south and east, but it could not approach nearer than

TABLE IVc. (*continued*).—Coast Mist and Drizzle.

Date.	Time.		Duration.	Surface Wind.		Remarks.
	From	To		Direction.	Velocity.	
1917.	h.	h.	hrs.		m.p.h.	
28 June	2	7	6	E-S	23-10	
7/8 July	18	6	13	E-S-SW	8-15	
9 ,,	5	8	4	W-N	10-20	
17/19 July	17	4	36	S-W	19-42	
22/23 ,,	21	2	6	E	8-10	Coast mist only.
24 ,,	3	6	4	S-SW	3-5	,, ,,
24/25 ,,	21	6	10	SW-W	10-18	
26 ,,	8	11	4	WSW	16-20	
28 ,,	3	6	4	W	5-10	,, ,,
5 Aug.	5	...	1	NNW	10	,, ,,
8 ,,	1	11	11	S-Indef.-NW	26-8	
10 ,,	15	17	3	S	26	
22 ,,	8	10	3	S	27-31	
27 ,,	11	17	7	S-SW	25-35	
31 Aug.–1 Sept.	23	5	6	SW	26-33	
3 Sept.	22	...	1	SE	10	,, ,,
4 ,,	1	5	5	SE	13-18	,, ,,
4/5 ,,	22	7	10	S	4-16	
5/6 ,,	19	6	11	SE-NE	6-11	,, ,,
8 ,,	20	24	5	W-SW	14-17	
9 ,,	3	5	3	W	6-9	,, ,,
10/11 Sept.	13	11	23	Indef.-NE	0-12	
25/26 ,,	6	16	34	SW	5-24	
7 Oct.	6	11	6	SW-W	24-34	
12 ,,	7	18	12	SW-W	8-35	
16 ,,	15	20	6	SW	9-16	
21 ,,	16	18	3	SW	18-19	
31 Oct./1 Nov.	10	1	15	S-W	19-27	

about 2 miles. It seemed to fluctuate or pulsate, alternately clearing and coming on. There was practically no wind at the time. It seemed that the sun was acting a double part by first dissipating the fog as it came up, and then by means of heating up the ground where the fog had gone and thus causing convection currents it drew the fog up from the sea again. That convection currents were set up was evident from the fact that although the fog disappeared, masses of fracto cumulus and stratus appeared overhead and drifted off slowly in the light upper wind. A kind of unstable equilibrium continued during the day until near sunset a definite SW breeze caused the fog to completely envelop the peninsula.

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Coast mist and drizzle (Table IVc.) with very few exceptions occur only with winds from between SE and W, *i.e.* those with a southerly component. Their occurrence is almost always coincident with the forefront of well-developed depressions. They are not restricted to any particular season of the year, nor during any one month are they more frequent than at others. No velocity of wind seems capable of dissipating these mists. A change in the character and direction is necessary, and it is that change that almost invariably occurs after the passage of the trough of a depression. They become most persistent with a steady SW breeze. There seems to be no connection between their formation and the rising and setting of the sun as there is with the radiation fogs, that is to say, they set in and disappear at all times of the day and night.

There are a few exceptions of coast mists with N and E winds. In these cases they are true coast mists without any rain or drizzle and are not connected with the approach of depressions.

Extract from my report at Mullion on weather during October 1916:—

A large proportion of these wet mists have been observed to form through the upward deflection of a saturated current approaching the high ground in the vicinity of the Air Station. Thus it has been observed that when the sky is cloudless on the coast the Station is obscured by low clouds.

Thunderstorms.

Local weather conditions do not favour the development of thunderstorms in summer time. This is no doubt due to the insular position of this Station, situated as it is with sea on every side except the north-east. Thus many thunderstorms that rage over the moors of North Cornwall and Devon never encroach upon the vicinity of Mullion.

The winter type of thunderstorm peculiar to the western seaboard of the British Isles frequently passes over this Station during that season, but these storms are not common and are always very brief. They are, however, very dangerous while they last owing to the low altitude of the clouds causing nearly every discharge to pass direct to earth.

Thundery conditions, which seldom develop into storms locally, are very apt to occur during the formation or passage of shallow depressions up the English Channel or Bay of Biscay.

The most spectacular storm witnessed during the period under review was described in my November weather report 1916, from which the following is extracted:—

On the 7th, between 9-10.30 a.m., a violent electrical storm swept over the Station, accompanied by a heavy fall of hail, much of which showed rough hexagonal outlines. Pieces picked up round the weather hut 10 minutes after the fall measured 1½ to 2 inches in diameter. None showed more than three concentric rings of growth, whilst pieces up to half an inch in diameter were perfectly transparent, proving them to have been formed in one upward journey. The lightning was vivid and frequent. 150 flashes were recorded in 75 minutes. The rear of the storm cloud showed well-developed mammato-cumulus structure seldom observed in this country.

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Extract from my monthly report at Mullion for January 1917:—

Between the 14th and 16th the Northerly type then prevailing caused much visible electrical activity, due, no doubt, partly to a shallow low situated in the Channel, partly to the juxtaposition of adjacent masses of air maintained at different temperatures by unequal radiation from land and sea. A glance at the map of the Cornish peninsula will show that with a NE type

TABLE V.—Record of Thunderstorms.

Date.	Time. G.M.T.	Remarks.	Surface Wind.	
			Direction.	Velocity.
1916.	h.			m.p.h.
28/29 Sept.	19-5	Lightning only.	NE	10-25
30 Oct.	21	Thunderstorm. Forked lightning.	SW	10-20
31 ,,	9	Thunderstorm reported at Helston (nothing visible or audible on Station).		
31 ,,	18-21	Lightning only. Sheet on south-east horizon.	SW	15-35
6 Nov.	2-4	Lightning only.	WNW	20-38
7 ,,	9-10	Thunderstorm—intense—great hail—unusual precipitation.	SSW	10-30
26/27 Nov.	20-4	Lightning only.	W-N	8-22
9/10 Dec.	23-6	Lightning 6 hrs. Thunderstorm 2 hrs.	SW	10-34
12/13 ,,	18-20	Lightning only.		
	24-1	Thunderstorm. Snow.	Indef.	4
14 Dec.	18-24	Lightning only.	N.	3-9
14 ,,	3	Thunderstorm.	NE	10-14
18 ,,	24	Thunderstorm. Trough of depression.	SW-WNW	16-23
21/22 Dec.	23-5	Lightning only.	SW	7-27
1917.				
8/9 Jan	21-4	Lightning only. Gale, squally.	N	
14/15 Jan.	18-6	Lightning only. Sleet.	NE	10-22
15 Jan.	22-24	Lightning only. Snow.	NE-ESE	15-26
16 ,,	7	Thunderstorm with snow.	NE	10-18
3 March	19	Thunder only.	SE	30
5 ,,	2-4	Thunderstorm.	S	10-16
11 ,,	20-21	Lightning only.	NNE	20
12 May	9	Distant thunder.		
26 ,,	21-23	Well-developed thunderstorm.		
7 July	21	Thunder heard in distance. No lightning.		
13 Aug.	18-19	Squally weather.	SW	20-30
14 ,,	1-3	Thunder. No lightning.		
9 Sept.	13	Thunder heard in distance.		
10 Oct.	19-22	Lightning only. Squally weather.	N	...
27 ,,	24	Thunderstorm. Squally weather.	WNW	...

two such currents would flow side by side without mixing, one keeping over sea, the other over land, and that a slight change towards an Easterly or Northerly type would immediately cause a disturbance. Such changes did occur during the 14th-16th.

The rare phenomenon known as "Globular" lightning was observed at Penzance at 5 p.m. December 20, 1916. It lasted for 15 minutes before exploding harmlessly. Observed from the station across Mounts Bay it was mistaken for a ship on fire.

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TABLE VI.—Local Signs of Approaching Depressions and their Relation to the Barometric Tendency.

First Cirrus Observed.		Description of High Cloud.	Time of Commencement of Unusual Visibility.	Other Signs of Depression.	Remarks on Movement of Depression.	Rate of Movement in m.p.h.	Time of 1st Fall Barometer.	No. of Hrs. Warning by 1st Sign.
Date.	Time.							
1916.	h.		h.				h.	
10 Aug.	15	Ci.-Cu.	...	...	...	...	2 (11th)	11
24 ,,	...	None observed.	...	High winds followed.	...	...	...	Nil
28 ,,	18	Ci.-St.	...	...	...	...	24	6
2 Sept.	...	None observed.	...	...	...	...	...	Nil
3 ,,	18	Common Ci. and Ci.-Cu.	...	Yellow sunset.	...	...	8 (4th)	14
11 ,,	...	None observed.	...	...	...	...	...	Nil
16 ,,	18	Common Ci.	...	Partial solar halo 18 hr.	...	...	10 (17th)	16
24 ,,	23	Common Ci.	...	...	...	...	24	1
26 ,,	7	Common Ci.	...	...	...	...	10	3
3 Oct.	...	None observed.	...	...	Depression moved NNE from W. Ireland to Scotland.	...	...	Nil
5 ,,	...	None observed.	...	...	Depression off W. Ireland moved NE across Scotland.	...	...	Nil
14 ,,	1	Ci.	...	...	...	40	2	1
16 ,,	7	Ci., then Ci.-Cu., then Ci.-St.	...	Solar halo 10-12 hr.	...	23	9	2
20 ,,	6	Ci.-Cu.	...	...	Depression moved from W. Ireland to SSE, then turned ENE and NE up the St. George's Channel.	10	10	4
24 ,,	...	None observed till 0900.	...	Brilliant sunset previous day.	Depression moved NNE from S.W. Ireland,	23	2	9
26 ,,	12	Common Ci., Band Ci., Ci.-St.	8	Solar halo.	...	13	17	9
28 ,,	7	Common Ci.	12	...	...	14	21	14
30 ,,	...	None observed.	...	Gale.	...	...	...	Nil
1 Nov.	14	Ci., Change Ci., Windy Ci., Ci.-Cu.	10	...	...	19	20 (2nd)	34
3 ,,	15	Ci.-St.	...	Pink sunset, pink sunrise, gale followed.	...	22	8 (4th)	17

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TABLE VI. (*continued*).—Local Signs of Approaching Depressions and their Relation to the Barometric Tendency.

First Cirrus Observed.		Description of High Cloud.	Time of Commencement of Unusual Visibility.	Other Signs of Depression.	Remarks on Movement of Depression.	Rate of Movement in m.p.h.	Time of 1st Fall Barometer.	No. of Hrs. Warning by 1st Sign.
Date.	Time.							
1916.	h.		h.				h.	
15 Nov.	12	Tail and Band Ci.	10	...	Depression moved SSE from Ireland to B. of Biscay.	31	22	12
20 ,,	12	Ci.	9	...	...	...	11 (23rd)	74
24 ,,	15	Ci., Ci.-St. (Flocculent).	...	Ripple alto-stratus.	...	49	20	5
8 Dec.	9	Band Ci. (crested structure), Ci.-St.	...	Partial solar halo.	Depression moved S from N. of Ireland to B. of Biscay.	22	12	3
17 ,,	10	Thread Ci., Cirro-Macula, Ci.-St.	...	...	...	...	24	14
19 ,,	11	Band and Thread Ci., Ci.-Cu.	13	...	...	20	20	9
20 ,,	12	Ci.-St.	...	...	...	39	23	11
21 ,,	11	Windy Ci.	...	...	...	...	18 (22nd)	31
24 ,,	9	Tail Ci., Ci.-Cu.	8	...	...	36	11	3
27 ,,	8	Tail, Windy, Band and Thread Ci., Ci.-Cu.	...	...	...	36	9 (28th)	25
1917.								
4 Jan.	9	Windy Ci.	12	...	...	55	10 (5th)	25
6 ,,	10	Band Ci., Ci.-St.	8	Solar halo.	...	25	24	16
10 ,,	...	None observed.	17	Ripple alto-stratus and mackerel sky 8 hr.	Depression moved S from Irish Sea to B. of Biscay.	58	16	8
12 ,,	9	Flocculent Ci.-St., Tail and Band Ci.	...	...	Depression moved SSE down N. Sea, stationary off N. of Holland.	23	6	−3
30 ,,	8	Thread and Tail Ci.	...	...	...	27	24 (31st)	40
17 Feb.	7	Band, Windy, and Thread Ci., Ci.-Cu.	...	...	...	...	23	16
19 ,,	7	Band Ci.	...	...	...	25	12	5
3 Mar.	11	Thread Ci., Ci.-St., Ci.-Cu.	...	Solar halo 14 hr.	...	...	21	10
5 ,,	12	Ci.-St.	9	...	...	25	24	15

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TABLE VI. (*continued*).—Local Signs of Approaching Depressions and their Relation to the Barometric Tendency.

First Cirrus Observed.		Description of High Cloud.	Time of Commencement of Unusual Visibility.	Other Signs of Depression.	Remarks on Movement of Depression.	Rate of Movement in m.p.h.	Time of 1st Fall Barometer.	No. of Hrs. Warning by 1st Sign.
Date.	Time.							
1917.	h.		h.				h.	
8 Mar.	11	Thread Ci., Ci.-St., Windy Ci.	...	Pink sunrise 7 hr.	...	...	21	14
9 ,,	16	Ci.-St., Thread Ci., Windy Ci.	...	Solar halo 16 hr., orange to salmon-pink sunset, lunar halo 21 hr.	...	25	4 (10th)	12
12 ,,	21	Ci.-St.	11 (13th)	Orange sunset 19 hr.	...	20	8 (13th)	13
17 ,,	18	Windy and Band Ci.	...	Yellow-gold sunset.	Depression moved from Iceland to Holland.	33	22 (18th)	28
24 ,,	10	Ci.-St., Band Ci., Thread Ci., Ci.-Cu., Change Ci.	...	Fiery red sunrise, pink sky 6 hr.	...	20	2 (25th)	20
27 ,,	8	Thread and Windy Ci., Ci.-St., and Band Ci.	8	Solar halo 13 hr.	...	9	2 (28th)	18
31 ,,	...	None observed.	6	Gale ensued next night.	...	18	12 (1st)	30
6 April	8	Windy Ci., Ci.-Cu., Thread Ci., Ci.-St., Band Ci.	13	Solar halo 12 hr.	...	11	4 (8th)	44
10 ,,	8	Ci.-Cu., Ci.-St., Thread and Band Ci.	12	...	Depression moved SE from N. Ireland to English Channel.	23	15	7
12 ,,	20	Ci.-St.	9	Orange sunset, lunar halo 3 hr.	...	33	11 (13th)	26
15 ,,	19	Thread Ci.	12	Salmon-pink to orange sunset.	Depression moved SE from Hebrides to Southern N. Sea.	53	7 (16th)	19
17 ,,	11	Windy Ci., Ci.-St.	8	Pink sunrise, solar halo 11 hr.	...	18	22	17
5 May	19	Common Ci., Ci.-Cu.	...	Sun pillar at sunset.	...	12	12 (6th)	17
15 ,,	...	None observed.	10	...	...	..	22 (16th)	36
19 ,,	17	Ci., Windy Ci., Change Ci.	...	Ripple alto-stratus, pink sunrise.	...	18	9	16
23 ,,	...	None observed.	...	Wind over 30 m.p.h.	...	...	...	Nil
25 ,,	5	Ci.-Cu.	...	Mackerel sky.	...	...	22	17

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TABLE VI. (*continued*).—Local Signs of Approaching Depressions and their Relation to the Barometric Tendency.

First Cirrus Observed.		Description of High Cloud.	Time of Commencement of Unusual Visibility.	Other Signs of Depression.	Remarks on Movement of Depression.	Rate of Movement in m.p.h.	Time of 1st Fall Barometer.	No. of Hrs. Warning by 1st Sign.
Date.	Time.							
1917.	h.		h.				h.	
1 June	18	Windy and Band Ci., Ci.-St., Ci.-Cu., Thread Ci.	23	...	...	...	16 (3rd)	46
21 ,,	5	Ci., Change and Windy Ci., Ci.-Cu.	22 (20th)	Pink sunrise.	...	...	12 (23rd)	62
24 ,,	22	Windy Ci.	7 (25th)	...	...	...	21 (26th)	48
4 July	9	Windy and Thread Ci.	...	...	Depression moved NE from B. of Biscay to SE England.	23	22 (5th)	37
16 ,,	8	Thread Ci.	22	Pink sunrise 4 hr.	...	30	14 (17th)	34
9 Aug.	5	Common Ci.	9	Partial solar halo 17 hr., pink sunrise 4 hr.	Depression formed S. of Ireland and moved northward.	15	10 (10th)	30
16 ,,	6	Common Ci., Thread Ci., Ci.-Cu.	22 (15th)	Partial solar halo.	...	12	21	23
19 ,,	19	Ripple Ci.-St., Ci.-Cu.	21 (18th)	...	...	17	14 (20th)	41
25 ,,	10	Common Ci.	21 (24th)	Salmon-pink sunrise 5 hr.	...	18	10 (25th)	13
26 ,,	...	None observed.	21 (26th)	Pale yellow sunset 19 hr.	...	21	23	4
29 ,,	19	Windy Ci.	22	...	...	31	10 (30th)	12
31 ,,	19	Ci.-St.	9	Solar halo 19 hr., red sunrise, pink sky 6 hr.	...	45	20 (31st)	14
2 Sept.	15	Windy Ci.	20	Yellow sunset, pink sky 6 hr.	...	19	9 (3rd)	27
12 ,,	15	Common Ci., Ci.-St., Windy Ci., Ci.-Cu.	2	Pale yellow sunset.	...	33	24 (12th)	22
3 Oct.	9	Ci.-Cu.	...	...	...	...	9 (3rd)	Nil
4 ,,	21	Common Ci.	20	...	...	...	23 (5th)	27
6 ,,	...	None observed.	19	...	...	...	20	1
7 ,,	...	None observed.	24	...	...	...	10 (8th)	10
10 ,,	7	Common Ci.	...	...	...	...	10 (11th)	27
21 ,,	...	None observed.	19 (21st)	...	...	...	9 (22nd)	14
23 ,,	...	None observed.	19 (23rd)	Gale followed.	...	...	9 (24th)	14

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Notes on Local Signs of the Approach of Depressions.

In a few cases detailed in the above Table, no warning sign was observed. In most of these, the lower clouds no doubt masked the cirriform skies.

During the summer months it is sometimes very difficult to distinguish between the cirrus of a fine summer day and that due to approaching bad weather.

There seems to be no simple connection between the rate of movement of a depression and the number of hours of warning by local signs.

Unusual visibility as a rule precedes the first appearance of cirrus.

52 per cent of the depressions tabulated were preceded by the phenomenon of unusual visibility.

Remarks on Depressions.

It is noteworthy that on two occasions during March 1917, when the centre of a depression passed over this Station, not only were there the

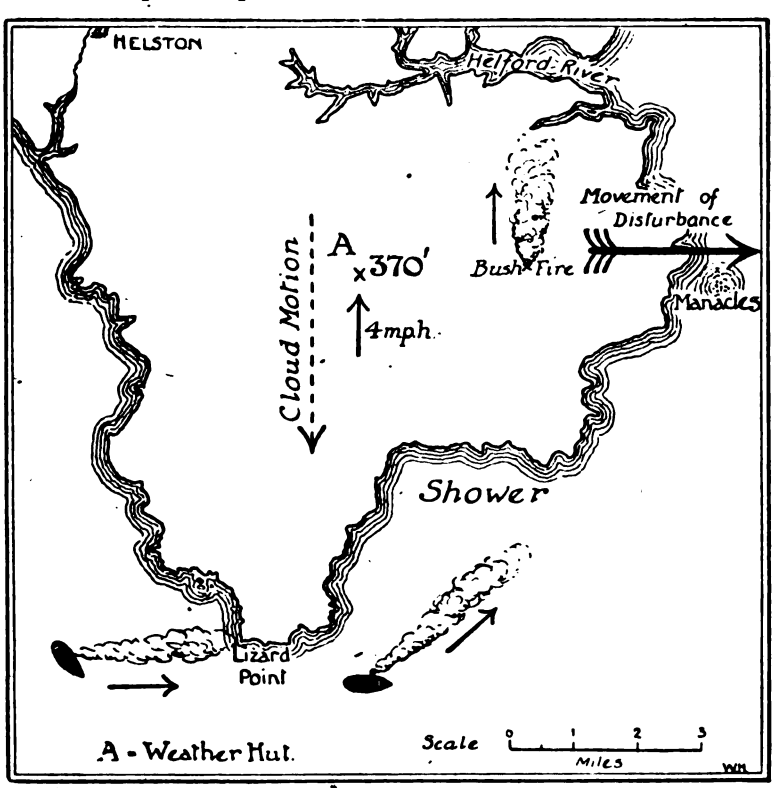

Fig. 2.—Showing surface wind directions at 16·30 G.M.T., April 7, 1917, during passage of depression.

usual calms coincident with the minimum pressure, but the weather became fine and the sky almost cloudless, and remained so without showers or squalls while the depression passed away.

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TABLE VII.—Table showing Connection between Unusual Visibility and Windy and Rainy Weather.

Date.	A. Time first appearance.	Duration.	Nature.	B. Time of Increase of Wind to 25 m.p.h.	Number of hours between A and B.	C. Time of Commencement of Rain.	Number of hours between A and C.	Remarks.
1916.	h.	hrs.		h.		h.		
15 Oct.	10	7	Variable.	Wind 40 m.p.h.	...	Showery at time.	...	
16 ,,	9	8	Coloured.	8 (17th).	23	14.	5	
24 ,,	7	5	do.	12.	5	12.	5	Gale followed.
25 ,,	10	3	do.	17.	7	Showery at time.	...	
26 ,,	8	7	do.	19.	11	do.	...	Heavy gale followed.
28 ,,	12	5	do.	Wind 30–40 m.p.h. at time.	...	do.	...	Gale followed.
1 Nov.	10	20	do.	24 (2nd).	38	do.	...	do.
6 ,,	11	2	do.	Wind 29 m.p.h. at time.	...	18.	7	Gale same night.
15 ,,	10	2	Grey.	Wind 30 m.p.h. at time.	...	1 (17th).	38	Gale next day.
20 ,,	9	48 intermit.	Coloured.	do.	...	Showery at time.	...	Gale 23rd (20 hrs. after v. ceased).
25 ,,	20	5	do.	Wind 30–40 m.p.h. at time.	...	Passing showers at time.	...	
26 ,,	11	12	do.	Wind 20–30 m.p.h. at time.	...	do.	...	
27 ,,	11	6	do.	No wind followed.	...	18 (28th).	31	
28 ,,	7	12	Grey.	do.	...	18.	11	
29 ,,	6	9	do.	do.	...	No rain followed.	...	
30 ,,	7	2	Coloured.	20 (1st).	37	do.	...	
3/4 Dec.	14	26	do.	15.	1	Passing showers at time.	...	
5 ,,	8	2	do.	No wind followed.	...	do.	...	
13 ,,	5	3	do.	do.	...	6.	1	
15 ,,	13	4	do.	do.	...	16.	3	
19 ,,	13	4	Grey.	7 (20th).	18	24.	11	
22 ,,	12	5	Coloured.	23.	11	22.	10	
24 ,,	8	4	Grey.	17.	9	22.	14	
1917.								
4 Jan.	12	7	Coloured.	Wind 30 m.p.h. at time.	...	3 (5th).	15	
5 ,,	10	4	do.	16.	6	17.	7	
6 ,,	8	15	do.	12.	4	9.	1	
7 ,,	8	4	Grey.	15.	7	12.	4	Gale same evening.
8 ,,	9	2	Coloured.	Gale at time.	...	Passing showers at time.	...	
10 ,,	17	2	Grey.	24.	7	20.	3	
23 Feb.	8	2	do.	13.	5	10.	2	
27 ,,	16	2	do.	No wind followed.	...	No rain followed.	...	
28 ,,	14	10	do.	12 (2nd).	46	12 (2nd).	46	
1 Mar.	8	13	do.	12 (2nd).	28	12 (2nd).	28	

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TABLE VII. (*continued*).—Table showing Connection between Unusual Visibility and Windy and Rainy Weather.

Date.	A. Time first appearance.	Duration.	Nature.	B. Time of Increase of Wind to 25 m.p.h.	Number of hours between A and B.	C. Time of Commencement of Rain.	Number of hours between A and C.	Remarks.
1917.	h.	hrs.		h.		h.		
2 Mar.	8	4	Grey.	12.	4	12.	4	
5 ,,	9	5	Coloured.	Wind 25 m.p.h. at time.	...	Passing showers at time.	...	
6 ,,	16	4	do.	21.	5	No rain followed.	...	
13 ,,	11	2	do.	15.	4	14.	3	
14 ,,	7	12	do.	Wind 25 m.p.h. at time.	...	No rain followed.	...	
15 ,,	10	5	do.	11.	1	do.	...	
18 ,,	10	8	do.	Wind 30 m.p.h. at time.	...	16 (19th).	30	
22 ,,	8	11	do.	do.	...	No rain followed.	...	
23 ,,	12	3	do.	Wind 25 m.p.h. at time.	...	6 (25th).	42	
26 ,,	15	3	do.	Gale at time.	...	Passing showers at time.	...	
27 ,,	8	11	do.	9.	1	8 (28th).	24	
30 ,,	9	10	do.	Wind 30 m.p.h. at time.	...	Passing showers at time.	...	Gale same day.
31 ,,	6	12	do.	9.	3	do.	...	
1 Apr.	9	9	do.	Wind 28 m.p.h. at time.	...	17.	8	Gale same night.
2/3 ,,	21	6	do.	4.	7	4.	7	Snow on ground.
3 ,,	20	5	do.	9 (5th).	37	11 (4th).	15	
6 ,,	13	8	do.	Wind 26 m.p.h. at time.	...	1 (7th).	12	
7/8 ,,	13	19	Grey.	13 (8th).	24	Passing showers at time.	...	
10 ,,	12	4	Coloured.	Wind 34 m.p.h. at time.	...	20.	8	Gale same night.
12 ,,	9	11	do.	1 (14th).	39	21 (13th).	36	
13 ,,	14	6	do.	1 (14th).	10	21.	7	
15/16 ,,	12	10	do.	Wind 32 m.p.h. at time.	...	Passing showers at time.	...	Intermittent.
17 ,,	8	6	do.	1 (18th).	17	3 (18th).	19	
19 ,,	9	4	do.	Wind 30 m.p.h. at time.	...	No rain followed.	...	
28 ,,	10	5	do.	No wind followed.	...	do.	...	
29 ,,	11	4	do.	do.	...	do.	...	
15 May	10	9	Variable.	10 (17th).	48	24.	14	
1/3 June	23	28	Coloured.	8 (2nd).	9	24.	1	
3/5 ,,	15	36	do.	Wind 30 m.p.h. at time.	...	No rain followed.	...	
8/10 ,,	14	46	do.	No wind followed.	...	do.	...	
12/13 ,,	20	7	do.	11 (13th).	16	13 (13th).	18	
17/18 ,,	21	6	do.	No wind followed.	...	16 (18th).	20	
20/22 ,,	22	30	Variable.	do.	...	Passing showers at time.	...	
22/23 ,,	12	27	do.	23 (23rd).	33	17 (23rd).	29	

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TABLE VII. (*continued*).—TABLE SHOWING CONNECTION BETWEEN UNUSUAL VISIBILITY AND WINDY AND RAINY WEATHER.

Date.	A. Time first appearance.	Duration.	Nature.	B. Time of Increase of Wind to 25 m.p.h.	Number of hours between A and B.	C. Time of Commencement of Rain.	Number of hours between A and C.	Remarks.
1917.	h.	hrs.		h.		h.		
24/26 June .	22	51	Variable.	No wind followed.	...	2 (26th).	29	
8/9 July .	22	3	Grey.	24.	2	Passing showers at time.	..?	
14/15 ,, .	22	5	Coloured.	7 (15th).	10	2 (15th).	5	
16/17 ,, .	22	6	do.	2 (18th).	29	16 (17th).	19	
25 ,, .	9	10	do.	15 (26th).	30	18.	10	
26 ,, .	1	3	Grey.	15 (26th).	15	2.	1	
26/27 ,, .	22	5	do.	No wind followed.	...	8 (27th).	11	
28/30 ,, .	10	50	Variable.	12 (30th).	49	5 (29th).	18	Intermittent.
31 July/1 Aug.	21	7	Coloured.	9 (1st).	13	5 (1st).	9	
1/2 Aug. .	16	10	Variable.	Over 30 m.p.h. at time.	...	20.	4	Intermittent.
2 ,, .	21	3	Grey.	11 (3rd).	15	20 (3rd).	24	
6 ,, .	21	3	Coloured.	15 (7th).	19	17 (7th).	21	
12/13 ,, .	21	7	Grey.	7 (13th).	11	Passing showers at time.	...	
14 ,, .	1	4	do.	16.	16	Rain at time.	...	
14/15 ,, .	22	7	Coloured.	15 (15th).	18	Passing showers at time.	...	
15/16 ,, .	22	7	do.	5 (17th).	32	4 (16th).	7	
16/17 ,, .	21	8	do.	5 (17th).	9	4 (17th).	8	
18 ,, .	1	4	do.	Gale at time.	...	3.	2	
26/27 ,, .	21	7	do.	9 (27th).	13	4 (27th).	8	
29/30 ,, .	22	4	Variable.	10 (30th).	13	2 (30th).	5	
31 ,, .	9	6	Coloured.	23.	15	18.	10	
6 Sept. .	23	1	do.	14 (7th).	16	19 (8th).	44	
8 ,, .	1	17	do.	17.	17	19.	19	
12 ,, .	2	4	do.	9.	8	18 (13th).	39	
16/17 ,, .	22	7	Variable.	9 (17th).	12	3 (17th).	6	
19/20 ,, .	20	10	do.	10 (20th).	15	14 (20th).	19	
19/20 Oct. .	18	13	Coloured.	20 (20th).	26	24 (20th).	30	

N.B.—Grey visibility is the variety usually seen under a sky uniformly overcast with stratus or alto stratus when objects stand out almost in silhouette against the horizon. Coloured visibility is that kind when objects are seen under direct sunshine in their natural colours.

Winds of 25 m.p.h. are those which attain that velocity in gusts, the mean velocity being somewhat lower.

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On April 7, 1917, at 16.30 G.M.T., when there was little pressure gradient, the clouds moving from the north with a velocity of about 10 m.p.h., the following surface wind directions were observed in the vicinity, as shown in Fig. 2:

Smoke from a vessel to SW moving slowly E.
Smoke from a vessel to S moving slowly NE.
Smoke from a bush fire to E moving slowly N.
Light air recorded by anemometer S 4 m.p.h.

A pilot balloon with zero-lift was immediately released in the hope of watching it move round what appeared to be a circular wind system, but it was unfortunately lost to view owing to the contour of the surface in the vicinity of the Helford River.

This miniature depression caused a large belt of dark cumulus overhead which did not reach to the horizon in any direction. Its extent appeared to be confined to the immediate vicinity of the Lizard peninsula, to which it was no doubt indirectly attributable. The circulation was sufficient to cause a short sharp shower over the sea to the south-east. The whole moved away in an etaserly direction.

From an examination of Table VII. it is obvious that there is a marked connection between unusual visibility and strong winds and rain. That is, it is generally the precursor of both.

If the cases are eliminated in which the wind, at the time of the first appearance of unusual visibility, was over 25 m.p.h. the Table shows that in

61% the phenomenon was followed by winds of 25 m.p.h. or over within 24 hours;

19% the phenomenon was followed by winds of 25 m.p.h. or over within 24-48 hours;

20% the phenomenon was not followed by winds of over 24 m.p.h. within 48 hours.

In most of these last cases the visibility was coloured.

If the cases are eliminated in which rain or passing showers were recorded at the time of the first appearance of unusual visibility, the Table shows that in

64% the phenomenon was followed by rain within 24 hours;

20% the phenomenon was followed by rain within from 24 to 48 hours;

16% the phenomenon was not followed by rain within 48 hours.

Out of a total of 43 cases where unusual visibility preceded both wind and rain—

the rain preceded the wind in 26 cases;
the wind preceded the rain in 12 cases;
wind and rain came simultaneously in 5 cases.

Thus showing this phenomenon to be a more sure prognostic of rain than of wind of velocity of 25 m.p.h. or over.

The following observations of sunset and sunrise skies, which are really eye estimations of the interference tints produced by the refraction of horizontal rays of sunlight passing through the atmosphere, do not support old weather lore and shepherds' maxims as infallible. They do seem to indicate, however, that brilliant skies are precursors of windy weather.

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TABLE VIII.—Optical Phenomena during March 1917.

Sunsets. Colour of Sunset.	Sequence of weather in next 24 hours. Wind. Maximum Gust Velocity.	Weather.
	m.p.h.	
Orange	25	Showery.
Brilliant yellow	30	...
Yellow	35	Showery.
Orange-salmon pink	38	Rain. Mist.
Orange	28	Rain.
Orange	25	Fine.
Orange, sun-fiery red	25	Fair.
Fiery red	30	Fine.
Yellow-gold	30	Fine.
Yellow-pink	30	Fine to showery.
Yellow-orange	35	Showery to fair.
Yellow-orange	25	Fair.
Yellow-pink	30	Fine. Fair.
Orange-salmon	35	Rain, mist.
Salmon-pink	Gale.	Rain.
Crimson	31	Snow showers.
Sunrises. Colour of Sunrise.		
Pink	Gale.	Snow and rain showers. Mist next morning.
Pink	25	Fair to fine.
Yellow	30	Slight shower.
Yellow	30	Fine.
Pink	25	Calm at night. Fine.
Pink, sun-fiery red	30	Rain in 24 hours' time.
Pink	Gale.	Rain. Mist.

Temperature.

The most obvious of the local peculiarities of this element is the small diurnal range—a striking proof of the tempering effect of the surrounding seas.

During the thick weather so often experienced with southerly winds the diurnal range falls almost to zero, and at times, especially during the winter, there is an inversion of temperature—the maximum occurring in the night, the minimum in the day.

TABLE IX.—Diurnal Range 1916–1917.

Month.	Mean Range.	Maximum Range.	Month.	Mean Range.	Maximum Range.
	° F.	° F.		° F.	° F.
Dec. 1916.	...	11·5	June 1917.	13·2	20
Jan. 1917.	5·2	10·5	July ,, .	10·3	15
Feb. ,, .	6·8	12	Aug. ,, .	9·5	17
March ,, .	9	18	Sept. ,, .	8·8	14
April ,, .	13·7	24	Oct. ,, .	9	14
May ,, .	12·6	25			

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Temperature changes are very sudden during the north-west squally type of weather—differences of as much as 12° F. have been recorded in as many minutes during the passage of intense squalls.

The larger ranges shown in the above Table from April to June were due to the large proportion of bright fine weather at this period. This part of the year is considered to be the best from the point of view of sunshine and absence of rain, by most local observers.

DISCUSSION.

The PRESIDENT (Mr. R. H. HOOKER) said they were very much indebted to Lieut. Silvester for his paper, which ought to be extremely interesting to all airmen. He would like to ask if the columns headed "diurnal range" and "maximum range" in Table I. both referred to gustiness, because if so he did not quite see how it was that the maximum range in column 13 was often less than the diurnal range in column 10; if they did not, some further explanation of "diurnal range" was necessary.

Mr. M. A. GIBLETT called attention to the fact that in the diagram the direction of the wind was made to coincide with the smoke track from the Steamers. This could only be the case if the ships were stationary or moving up or down wind. The smoke tracks shown might easily be produced by a light Southerly wind like that indicated at two places on land, *e.g.* if the ship on the left of the diagram were moving slowing north-west and the other slowly west. Then all suggestion of a circulation vanished.

With regard to mammato-cumulus cloud being seldom observed, this is no doubt true, since the development is very local and easily missed by a network of observing stations. However, he did not regard it as of very rare occurrence. Early in the paper it was suggested that the bumpiness experienced when flying over a certain area was due to the relative wetness of the ground. Was the suggestion that the thermal properties of the ground were thus rendered irregular and that convection currents were then set up under insolation?

Mr. R. INWARDS asked if the proverb "The North wind goes to bed at night" was a local one.

Capt. C. K. M. DOUGLAS said that the winter thunderstorms of the Northerly type were always associated with very low upper air temperatures between 10,000 and 15,000 feet. The passage of the cold current over a warm sea causes a very high lapse rate of temperature, which is the chief cause of the thunderstorms, though the horizontal temperature gradient mentioned by Lieut. Silvester no doubt also contributed to their development. He agreed with Mr. Giblett that mammato-cumulus cloud structure was not a really rare phenomenon. It was interesting that a connection should be established between unusual visibility and the approach of a depression at a station usually free from the smoke which impairs visibility observations in many localities.

Mr. F. J. W. WHIPPLE said that the division of fogs into three classes was very interesting. It was customary to distinguish between radiation fog and sea fog, and he had regarded coastal fog as merely sea fog which had drifted ashore. Lieut. Silvester had discussed coastal fogs which occurred when there was no fog at sea; these occurred when a considerable wind was blowing off the sea, and it might be that they were to be explained by the retarding effect of the friction over the land. Some of the air would be forced upward and this would lead to the formation of very low cloud which would appear as fog on the plateau.

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Lieut. N. L. SILVESTER, in reply to the President, said that the "diurnal range" referred to in Table I. was that of the mean wind velocity during the day, not of the velocity in gusts. In reply to Mr. Giblett he said that he believed he had got the information about mammato-cumulus cloud structure from the *Meteorological Glossary*, and took it for granted that it was correct. With regard to the bumpiness over the moors, Lieut. Silvester said that he considered this to be analogous to an effect observed at Milton in Pembroke. One hot sunny day in July 1916 when the surface wind was light, a pilot balloon with zero lift was released from the top of a low hill. It moved slowly over a broad shallow valley keeping close to the ground until it reached a marsh in the valley bottom, when it rose rapidly out of sight, but returned to the surface near the weather hut on the farther side of the valley. There was evidently strong convection due to the increased humidity of the air over the marsh. In reply to Mr. Inwards, he said that he probably heard of this proverb relating to the nocturnal behaviour of the North wind whilst in Cornwall, but he was not sure.

Mr. S. C. RUSSELL writes: Reference has been made to the rareness of mammato-cumulus cloud in this country, which is scarcely borne out by observation. During the years 1903–1910, at Epsom, Surrey, this cloud was seen on 67 occasions, the maximum number of days being 13 in 1907 and 1908 to 3 only in 1905, averaging 8 days per annum during the period. On the Lancashire coast the cloud is apparently seen even more frequently, passing under the popular description of "Rain Balls." During August 1916, near Fleetwood, I observed the cloud on nine days during the month.

Professor H. H. Hildebrandsson.

Professor H. H. Hildebrandsson, writing to me from Upsala on 12th May 1920 to record his thanks for the presentation of the Symons Medal, takes occasion to remind me of the inaccuracy of my remark that I had never seen him in London. He recalls that a meteorological party, of which he was one, on the way to the meeting of the International Committee at Southport in 1903, dined together in London by my invitation. Others besides myself will doubtless remember the occasion, which at the moment had slipped from my memory. NAPIER SHAW.

Forecasting of Swell on the Morocco Coast.

This subject, mainly as affecting the Port of Casablanca (Dar-el-Beida), is discussed in the undermentioned paper[1] and is an extension of an enquiry first initiated in May 1913. Dr. Gain deals with the period 1915–1918 and gives the result of a study of 210 depressions, dividing them into four types: (1) Depressions passing anywhere between Iceland and Ireland, and coming from the Ocean Region to the North of the Azores; (2) Depressions forming in the region of the Azores and having an Easterly path; (3) Depressions passing to the North of Iceland; (4) Depressions having a trajectory more or less North and South, passing Southward between Iceland and Norway, making for the British Isles, Central Europe, or the Mediterranean. Out of the 130 depressions of type (1), 92 caused swell at Casablanca and 38 were without effect. Of the 31 of type (2), 24 produced in general a slight swell, 7 gave no swell. The 36 depressions of type (3) gave no swell at Casablanca, and of the 13 of type (4), 6 gave some swell and 7 no effect. Dr. Gain maintains that the forecasting of swell at Casablanca is possible, 24–48 hours before its actual arrival, in 90 per cent of the cases likely to occur. SPENCER C. RUSSELL.

[1] *La Prédiction des Houles au Maroc* (par L. Gain, Adjoint au Chef du Service de la Météorologie Maritime). Service Hydrographique de la Marine, volume de 1918, Paris.

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THE SURREY HAILSTORM OF JULY 16, 1918.

By J. EDMUND CLARK, B.Sc., F.R.Met.Soc.

[Received October 13, 1919—Read April 21, 1920.]

About 1.45 a.m. July 16, 1918, a brief storm with faint lightning, thunder and gentle rain was centred north-west from the zenith at Asgarth, Purley ($14\frac{3}{4} : \frac{1}{2}$ [1]). At 2.15 violent thunder and lightning began, with heavy rain and hail. In a minute furious blows were struck on the southern and western windows by huge chunks of ice, the thunder becoming inaudible and the sound deafening; this continued for about six minutes without the slightest slackening. Flashes showed that the hill-sides were white. The illumination of the falling chunks by the almost incessant lightning made the nearer pieces seem stationary against a sheet of light reflected from those more distant. In about 9 or 10 minutes from the start the hail had entirely ceased and the rain soon after, though the thunderstorm continued violently. On going out, I found all but two panes of the greenhouse roof smashed and most of the glass in the frames. Round the house on the south and west the hail was two or three inches deep and far more in angles; on the level, although scattered most unevenly, about an inch deep. The storm cloud gradually passed off to a little south of east, having come from slightly south of west—although the wind was SSW as shown by the direction in which the hail struck and the debris lay. At about 2.40 a.m. there lay along the horizon from north-east to south-east a dull, lurid band of early twilight sky, perhaps 10° wide, the next 15° to 25° being occupied by an intensely dark stretch of cloud, apparently at a low elevation. Above this the clouds were of more normal type. The heavy mass, constantly lit up by lightning and sheet lightning, lasted on till full dawn, say 3.30 a.m. The appearance of the cloud as seen by Mr. J. Reeve near East Croydon Station (17 : 1) was like a "long straight black snake" which seemed to come up from the south-west, moving "as if drawn like a blanket by an unseen hand" towards the Crystal Palace (due north), and then coming back overhead, passing off to the east over the Shirley Hills. There was a narrow band of light above and below at each end. The hail fell on its return 5 or 6 minutes after it was first seen.

From my old gauge I poured out about 0·70 in. of rain. Twenty stones picked out sixteen hours after the storm from a heap across the road, still 40 ft. long, 5 broad, and nearly 6 in. thick, gave an average weight of $\frac{3}{4}$ oz.

When the hailstones struck the windows there was a phosphorescent flash of light.

Besides broken glass, the damage done was very great—the whole garden being devastated. Leaves and twigs were strewn thickly everywhere, most of the plums and fully one-third of the small crop of apples brought down—the rest being nearly all badly bruised; even cobnuts were

[1] As datum line is taken a straight line from three-quarters mile west of Holmwood Station to North Bromley Station, 22 miles to the NE (43° E of N). Positions are given by miles along this line, followed by a second figure giving divergence from datum, or the word "datum," if on it. Most are to NW; or "–" is prefixed if to SE.

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cracked. Paint was deeply scored, flints were knocked out of the flint banks, and a corner broken off a block of sandstone in a rockery; a few fragments of tiles came off the roofs, and quantities of gravel were knocked off the rough-cast.

There was some further rain about 3 o'clock, the emptied gauge giving 0·10; the total fall was 1·03 as measured in the Snowdon gauge (probably some splashed out even here). Thus it is pretty certain that 0·80 fell in the 10 minutes of the heaviest part of the storm—to allow more than 10 minutes for this would be extreme; the beginning and end were so very sharply marked. Unfortunately, I was too much engaged with seeing after wreckage to note the precise time when it stopped.

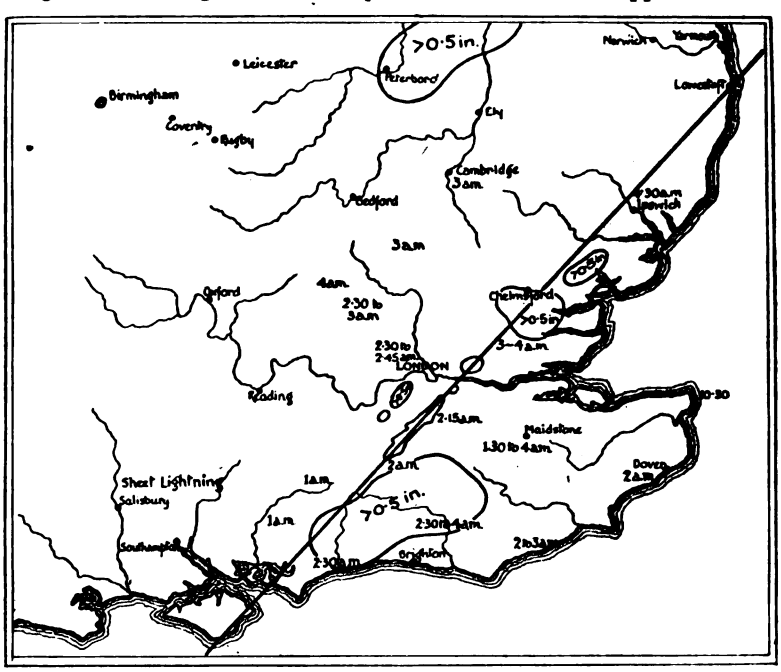

FIG. 1.—Showing the area affected by the thunderstorms, as reported to the Meteorological Office, for the rainfall day, July 15, 1918. The line from the Isle of Wight to Lowestoft is the prolongation of the axis of worst hail damage. The most severe destruction occurred in a narrow area, 22 miles long, stretching from west of Holmwood Station to North Bromley Station.

The hail was of three main forms, which were still thoroughly distinct in the heaps at six o'clock. The largest had an opaque core about $\frac{1}{8}$″ to $\frac{1}{2}$″ diameter, and were spherical or "bun-shaped" (not lens-shaped) with jagged protuberances, some of which were nearly an inch long. Across the protuberances, even at six o'clock, many measured fully 2″, the solid centres being from $\frac{3}{4}$″ to 1″ across. Another form was entirely opaque, very hard, oval, to almost circular, from $\frac{1}{2}$″ to $\frac{3}{4}$″ across, shaped and looking like big sugar-plums. Mixed with these were ordinary opaque hailstones. There was also a quantity of rain, which presumably was quite warm, since at once on the cessation of the hail the melting was marked, and the streams down the Riddlesdown Road were roaring like a torrent.

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The *Thermograph* showed a drop of only 3°, from 62°·5 to 59°·5 F. This is my chief reason for supposing that the rain must have been warm, or surely the air would have been cooled much more, even in the absence of signs of a cold descending current. It had been at 71° the previous day, 67°·5 at 6 p.m., and was again at 62°·5 at 6 a.m. The wind at 10 p.m. on the 15th was gentle from S, but by 11 o'clock had risen to a breeze from SE. After the storm had finished, it again backed round to SE. During the storm its strength was so small that the angle of fall was at most 30° and ranged down to 10° from the vertical, as shown by marks on woodwork.

The lumps were not aggregated separate stones. Knobs nearly an

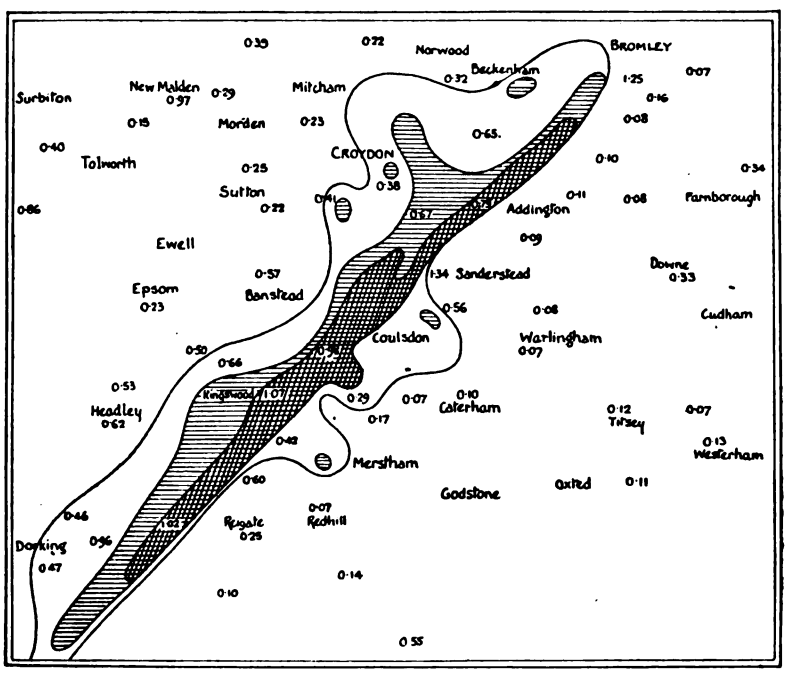

FIG. 2.—Showing the squall area in detail with all available rainfall data. The dark shading covers the area of heavy damage, the light shading that of some damage, the enclosing line that of hailfall.

inch long were often a bare quarter inch across at the base. Several had three such round their equator at even distances, with numerous shorter ones all over. In many cases there must have been fifteen to twenty knobs in all, or even more (see Fig. 3). Further, even the largest lumps had but one nucleus of opaque ice.

Taking the immediate locality, it was found that from two hundred yards to about six hundred yards up the road (S by E) the storm was far worse, the few houses and gardens suffering as much damage again, one or two windows and telephone wires being broken. The hail was also heavier. One sign of this was that, as said above, at 6 a.m. and later, the Purley Downs Golf Grounds across the valley were still white over a stretch distinctly off the storm line over Asgarth. This portion,

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about 400 yards wide, ran from west-south-west to east-north-east. South of it the hail ceased almost at once. Scars on the hedge bushes ended about 100 yards further up. Down the road serious damage lessened and ceased at 300 yards below Asgarth—a width in all of 1000 yards. Across the valley this was reduced to about six hundred yards. Photographs taken later of two clumps of elms, one two hundred yards down the road, the other two hundred yards up, show the difference. The latter look like winter.

Local.—West of the Riddlesdown Road the south-east margin continued sharply defined, with the worst damage close to its edge. Just inside, overlooking the Godstone Valley, at Skerryvore ($14\frac{1}{2} : -\frac{1}{16}$), by the corner of Oakwood Avenue and Downs Court Road, Mr. E. H. Finch's house had 150 tiles broken, and panes in leaded windows. Stones next morning measured $2\frac{1}{2}'' \times 2'' \times 1\frac{1}{2}''$ and his gauge caught 1·34 in., of which certainly 1·10 in. fell in the eleven minutes during which the hail lasted there, as timed by his youngest daughter. Equally

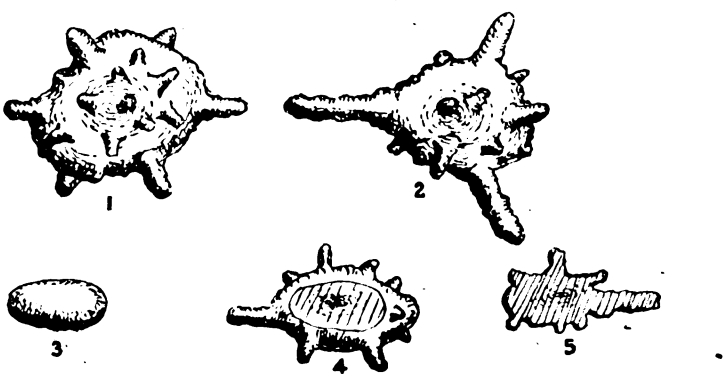

FIG. 3.—Sketches of hailstones (half scale) which fell at Asgarth, Purley. Nos. 4 and 5 are partly or wholly sectional.

large hailstones were measured on the other side of the Godstone Valley, at the far end of Higher Drive. In and near the Skerryvore garden nine dead birds were picked up. Lawns and even the Downs were pitted by the hailstones, some holes being two inches across, and nearly an inch deep. Similar pits remained even in loose soil, showing how suddenly the rain ceased after the hail. This slope and Little Roke suffered among the worst; the potatoes and other vegetables were completely destroyed, even large cabbages reduced to shapeless pulp. A semi-circular wire netting protection to young peas at Skerryvore was beaten flat and driven into the ground. As to houses, numerous SW windows were smashed in the Godstone Road near the County Council Boys' High School, also in the north-western half of Lenard Terrace and Little Roke Avenue parallel to it. The school was unusable, mainly from the deluge through the smashed skylights.

General Distribution.—Since, as the editor of the *Croydon Advertiser* put it, the papers were unable to publish or help, "thanks to the vagaries of the young lady known as Dora," an appeal for help was made to scholars in local high schools, and great assistance was rendered by those

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at the above Boys' School and the Croydon Whitgift and Girls' High School in Wellesley Road. Some 270 returns were thus obtained, which, with about 90 others, afford a good survey of the whole, showing that destructive hail fell in a fairly straight and unbroken band about half a mile wide from Holmwood in the south-west to Beckenham and Bromley, 22 miles distant, almost exactly to the north-east. Beyond Shirley, however, the cross section rather increased, and the violence diminished, hardly any damage resulting at Bromley.

Details along the Track.—Still confining attention to the storm axis it will be noted that it seems to have originated in the lowland east of Leith Hill (960 ft.), Holmwood Station being about 300 feet. Parts near the latter suffered. The postmaster, Mr. W. Crofts, living one mile north, reports damage to greenhouse roofs. Distant rumbling (mistaken for a sea engagement) was noted at 11 p.m. to the south-east. Travelling round by east toward London, it approached Holmwood from north-east, starting about 1.30 a.m. (corrected to true time as all through the paper). Hail began at 1.55, lasting to 2.5 at full force. The lightning was most vivid, the thunder and hail making tremendous uproar, increasing in force each moment until just after 2 o'clock. The hailstones were very large. Much gravel and stone was washed down the hillsides and roads, but no serious damage to crops, some only being beaten down. House slates were broken.

Hail fell in north-east Dorking, but no serious damage was reported even at Brockham, nearly two miles east (5 : $\frac{1}{2}$). This lies close to Betchworth (5 : $\frac{1}{4}$) and Buckland (6 : datum) where the damage was severe, and was vividly described in the *Surrey Mirror*, which braved the terrors of "Dora." Here terrific thunder and lightning preceded the climax. A loud roaring noise was heard; the dense hail obscured the light. Greenhouses were riddled, window panes smashed, trees stripped; vegetables of all kinds destroyed. The stones were like walnuts in size, many $1\frac{1}{2}$ inches across. Cereal crops were beaten down, the straw broken into three or more pieces, the green grain beaten out of the ears. The storm passed from south-west to north-east, the damage being confined to a strip of 800 yards, inside which "*everything growing has been destroyed, whereas the adjoining land remains unscathed.*" Here again roads were badly cut up, and green with leaves and twigs.

Passing up the slope of the Downs to Cheasleytown ($8\frac{1}{8}$: datum), Mr. E. H. Freshfield reports it as beginning at 2.8, and lasting eight minutes, half the time with unusual violence. No vertical glass suffered. Although coming from west-by-south the wind, deflected by the escarpment, made the hail fall from north-north-west.

At Walton-on-the-Hill (8 : 2) the reports tell only of slight damage to garden and field crops. At Tadworth it was much the same; Lieut. Spencer C. Russell at Spencer House (9 : $1\frac{3}{4}$) records distant thunder 1.15 a.m., last heard 2.38. At 2 o'clock lightning flashes were recorded sixty-five to the minute, heavy rolling peals varying between twenty-seven and forty-two seconds' duration. Hail fell from 2.11 to 2.19 a.m. but was not destructive. Another observer mentions some greenhouse breakage. At Kingswood Station Hotel ($9\frac{1}{2}$: $1\frac{1}{2}$) H. Hook gives the time as 2.10 a.m. and "about twenty minutes'" duration. Skylights and greenhouses were broken, and open transomes, but not shut

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windows. Hail fell straight down, big round balls; garden crops suffered heavily.

At Eyhurst (9⅞ : ½) D. Morphew puts the time at 2 to 2.15 a.m. and duration 10-15 minutes. Here again wheat grain was beaten clean out. Only one pane was broken. 1·07 in. of rain was measured at 9 a.m. More glass damage was done at Eyhurst Lodge (10¾ : ⅞). At Chipstead, near the pond (11 : ½), F. E. Goad gives 2.15 as "at its height," and duration about twenty minutes; 25 per cent of greenhouse glass was broken. The storm damage here was from ¼ mile up from the railway. The old-type gauge caught 0·87 in., probably equivalent to 1·10 in. Even thick rhubarb sticks were cut down or gashed, barrow loads of beet leaves, etc., collected, and potato haulm badly damaged. No damage occurred one mile due south, but much half a mile south.

At Portnalls, near How Green Reservoir (11¾ : ⅝), oat grain was cut clean out. Here 0·98 in. was measured by the Sutton District Water Co. At their valley station (12 : 1) very little hail fell and no damage was done. From How Green the track crossed on to the Brighton Road side of the spur, and here struck full upon Cane Hill Asylum, causing enormous damage in glass and crops, estimated at a total loss of some £1000. Indeed from here to Little Roke appears to have been the worst section, a stretch of about two miles (12½ to 14½). Cane Hill is half a mile north-west of the datum line; Little Roke on it. It is pretty certain that the downpour was greatest here also, but unfortunately no record is available except Mr. E. H. Finch's at the north-east end, already mentioned (1·34 in. at 14⅝ : −$\frac{1}{10}$). Cane Hill (per Mr. W. C. Smith, M.Inst.C.E., and Mr. R. H. Curtis) reports stones up to 2½ in. in length, irregular-shaped pieces of ice about ¾ inch thick, and 1 to 2 in. in breadth. At 6.30 a.m. about three cubic yards had been collected from the Asylum gutters. Close by here Mr. L. C. Gregory, Woodlands, Woodmansterne Road, reported a peculiar fusing at the fracture of some $\frac{3}{10}$-inch greenhouse glass on the ribbed underside, although he had not been aware of any special flash or crash of lightning. Coulsdon Court (13¼ : ¼ south-east) and Hartley and Bradmore Farms (13½ : ¼), on the high ground opposite Cane Hill, but more to north-east, suffered severely. Four fields of grain were ruined, and of course the greenhouses and frames at the Court, where the hailstones lay 3 in. deep, "jagged pieces of ice about the size of pigeon eggs, some larger, up to 5½ in. round." [This would be exclusive of the knobs.]

Continuing onward the storm crossed the valley of Old Lodge Lane, Old Lodge Farm (13¾ : datum) being at the worst part, although Reedham Orphanage, 700 yards north (14 : ⅜), had fully £300 of damage done. Indeed upon this section, after Cane Hill, the heavy destruction was over a width of at least a mile, for it embraced nearly all houses in the Brighton Road to within 500 yards of Purley Tram Terminus, which point is fully 1700 yards north-west of the Little Roke area (14½ : datum); glass suffered damage for at least a further ½ mile. A little further on, through Skerryvore (14⅝ : −$\frac{1}{10}$), the total width of damage to glass was still the full mile, from which maximum it rapidly fell off, to half a mile from just above Purleybury (15¼ : ⅓) in Purley Downs Road, up that road to just beyond Purley Beeches (15⅓ : datum).

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As instances of conditions along the Brighton Road, north from Smitham, at 2 Mount Pleasant on Stoats Nest Road, just off it ($13\frac{1}{2} : \frac{1}{2}$) a railway man had hail piled up in his rooms through his broken windows, and going out to work found heaps 1 to 2 feet deep. Several other reports speak of windows broken. Even across the valley, in Woodcote Grove Road, oats were flattened. Gladys Cox, Serlby, Woodcote Grove Road ($13\frac{1}{4} : \frac{3}{8}$), writes :—

> The hail came from south-west and was not in the usual form. Many large pieces of jagged ice were picked up in one bedroom, having been dashed through the windows. The storm appears to have swept across Coulsdon in a belt of limited breadth, as cultivated plots on the top at Woodcote were almost completely undamaged. The edge of the storm was seen by the grass, for some was knocked down, while the rest was standing up. The lightning was continuous ; not separate flashes.

This brings us to the Godstone Road and Riddlesdown area of more personal observation dealt with above. On the opposite (north-east) side, the next region to suffer severely lay in Sanderstead. Grain fields north-east of Purley Beeches ($15\frac{1}{2} : -\frac{1}{6}$) were here again beaten down, cut to pieces, and threshed out. At the Red House ($15\frac{3}{8}$: datum) on the Sanderstead Road, near the north-east corner of the Beeches, Capt. Alfred Carpenter, D.S.O., describes it as follows :—

> It ruined my garden and powdered the glass of my frames—I hear that yours is the same. Enormous hailstones fell. Most of them were round that came down the chimneys, about 30 in each room, and they rolled about the floor covered with soot, and we had to mop them up before they melted and spoiled the carpets. Most of my apples and damsons were knocked off. I had no other fruit, and the trees were hacked about—tomatoes, marrows and cucumbers were destroyed, and the potatoes beaten down, but the latter are recovering. By flashes of lightning we saw the hail pouring off the roof like snow. Notwithstanding the heavy *warm* rain that followed, the lawns remained white for half an hour, and, 9 hours afterwards, clusters of hailstones lay under the protection of the yew trees. In a cornfield near masses of ice were found late in the afternoon. The hail began at 2.20 a.m. and lasted ten minutes. In all my experience I have never seen or heard such hail. We had no windows broken. [His naval life included much service in the tropics.]

All frames and greenhouse roofs near by and above on Hook Hill were destroyed. 200 yards up the road, at Homecroft, corner of Britton Hill Road, so deep was the ice off the roof that a rose-bush was iced in by it some two feet deep. Elms at this corner ($15\frac{5}{8} : -\frac{1}{3}$) were stripped like those up Riddlesdown Road. The south-east margin had here swerved so as to include it and Britton Hill Farmstead ($15\frac{3}{4} : -\frac{1}{4}$). Thence the line swerved back rather more northerly to near the south-east end of Croham Hurst ($16\frac{1}{4}$: datum). The north-west margin for serious damage, after Purley Downs Road, was fairly well marked by the Penwortham Road to $\frac{3}{8}$rds on to Purley Oaks Road, there crossing the Oxted line and striking the Sanderstead Road below Beechwood Road ($16 : \frac{1}{3}$).

Coming now to Croham Hurst ($16\frac{1}{3}$: datum at south-east end ; summit 477 ft. ; Selhurst Road at Old Fox Farm at south-west, 300 ft.),

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this steep ridge in its half-mile south-east to north-west lies athwart and practically covered the width of heavy damage. Hail damage was confined to its south-east half, and yet far more destruction to its steep pebble slopes occurred on the north-west half. Thousands of tons were washed down the south-west slope facing the storm, starting from the very top and gathering volume, forming moraine-like piles in some parts of the lower slopes; in others leaving bare the underlying chalk and passing right out into the Selsdon Road. This implies that, where there was less hail, there was yet as much precipitation, but as rain, which of course more rapidly rushed down the slopes. No doubt the equally heavy downfall of the 17th inst. contributed, especially as coming on top of the other; but the latter fall was spread over an hour or two, not mainly concentrated into ten or fifteen minutes.

Ballards itself suffered severely. It occupies the western spur of the Shirley Hills, with the Croydon Water Works Reservoir just beyond ($17\frac{1}{3}$: datum: 475 feet), across the top of Coombe Lane, which falls west-by-north over 100 feet in a $\frac{1}{4}$ mile past Broadcombe Cottage, whence Mr. W. H. Mills sends the following valuable account:—

> Centre of storm when passing over the hills appeared to be a few yards (say 100) south-east of Valve House, where a few panes of glass were broken. Deep channels were made in the sides of the hills at Badgers Hole ($17\frac{3}{4} : \frac{1}{8}$) [a hamlet immediately adjoining Upper Shirley with which it is often confounded]. At one place the roadway, such as it is, was washed out to a depth of upwards of 4 feet. At the lower end of this small valley, some of the cottages had their crops buried under washed-down soil to a depth of from one to two feet. At my cottage potatoes were stripped of their leaves, the stems remaining with the tops broken off. Flints weighing about $1\frac{1}{4}$ lb. went bouncing down the road like indiarubber balls, and a blue brick weighing $7\frac{3}{4}$ lbs. was washed a distance of about 9 yards. The side of the road against my cottage was washed out to a depth of one foot in the recent storm.

At Upper Shirley just beyond Badgers Hole ($17\frac{7}{8} : -\frac{1}{4}$ to $+\frac{1}{8}$; altitude, 400 to 360 feet) the intensity was reduced, but the width was still nearly half a mile. "The scent from the surrounding pine wood of Addington Park," writes Mr. E. N. Mennell of The Hostel, "filled our bedrooms to such an extent that it was almost overpowering, although it was delicious immediately after the storm, which lasted forty minutes" (period of hail not stated). "The hail on our roof sounded like iron." He states that no damage was done to the glasshouses in Lower Shirley ($18\frac{1}{3} : \frac{1}{2}$) nor to allotments by the Church ($18\frac{1}{4} : \frac{1}{4}$), but that Addington Park Lodge ($17\frac{1}{2} : -\frac{1}{8}$) suffered severely.

Market gardeners at the lower end of West Wickham ($19\frac{1}{2} : \frac{1}{2}$) lost some glass. Peach trees on the walls were torn to shreds, and not a whole apple left. In places corn and hay were laid. "The hail was tremendous for size; it came down chimneys and hit the walls on the other side of the rooms."

There are no further records until Bromley ($22\frac{1}{4}$ north-east) where Mr. L. C. Bignold reported heavy hail, but next to no damage was done, nothing more for instance than the loss of a few dahlias. Hail fell also around Clock House ($20\frac{1}{2} : 1\frac{1}{2}$) but caused no damage.

It is interesting to note that these two records bring us to the area of the last destructive hailstorm in this district, associated with the

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widespread thunderstorm of June 14, 1914. Windows, greenhouses and gardens were then damaged over a considerable area, especially around Clock House, Kent House, New Beckenham, Penge, and parts of Bromley. The hailstones are described as being "as large and larger than acorns" and as "lumps of ice, some of them as broad as a half-crown piece." "Many were round and smooth as marbles, while others were like bits of blunt pencil." They consisted of transparent ice round an opaque core. This heavy hail lasted five minutes,[1] coming about 12.15 p.m. The area worst affected was marked out by the "mat of leaves and twigs strewing roads and paths." The storm itself began soon after noon and only ceased at 3 p.m.

Outlying Areas.—Having thus dealt with the strip of serious damage along the 22 miles from Holmwood to Bromley, conditions to the south-east and north-west must be looked at. Most astonishing is the rapid cessation nearly everywhere on the former margin, not only of any damage but even more of much rain. Remembering, indeed, that further rain fell both before and after the special thunderstorm, it seems doubtful whether any fell at all during its passage outside some half-mile from the axis of worst damage except at two points, Reigate and Kenley. At a distance from the axis up to 4 miles, records, 16 in all out of 23, vary from 0·07 to 0·11 inch. At Reigate the nearest reading is only 0·21. It may well be that the storm was here affected by striking against the abrupt scarp of the Downs. So also at Kenley (0·56 in., $14\frac{1}{2} : -\frac{3}{4}$) we have the deep north-west and south-east valley slope of Riddlesdown facing the storm full from where it was switching out of the main Brighton Road valley, up which a tongue of heavy damage projects nearly a mile. Bromley may be a third case, from the sharp rise behind Bickley to 300 feet.

On the north-west side, on the other hand, for a width of 10 miles, only one record (0·15 in. at Malden) is under 0·20 in., and falls of $\frac{1}{2}$ inch or more occur up to 3 miles from the datum line. Hail fell to a distance of 2, 3 or even 4 miles. Walton-on-the-Hill (7: 2) and Tadworth (9 : 2) have already been referred to. Wallington (15 : 3), Carshalton ($14\frac{1}{2} : 3\frac{1}{2}$), and even Sutton ($13\frac{1}{2} : 4$) were reached, as well as the north-western parts of Croydon ($19 : 3\frac{1}{2}$). A marked tongue both of hail and hail damage stretches here along the London Road, projecting 2 to $2\frac{1}{2}$ miles.

Here, however, come patches in exception. Some state that no hail fell (St. Stephens, London Road; Beatrice Avenue, Norbury; Auckland Road, Upper Norwood; Crescent Road, South Norwood), which at least shows that it was not enough to be noticed above the rain. One interesting record by Muriel Baker, Birchanger Road, reports it about 1.40 to 2 a.m. (perhaps too early), "then there was most heavy rain, then hail again for a few minutes." She assigns 20 minutes to the hail, "but as it rained and hailed together it was difficult to say."

Part of the same thunderstorm group, though more independent of the main storm axis, were two centres of heavy fall, one well to the south-east, the other to the north-west. Records in the former include Cuckfield, 1·50 in.; Balcombe (0 : − 12), 1·31 in.; Ardingly, 1·57 in.,

[1] From the *Beckenham Journal*, June 20, 1914, kindly procured for me by Mr. C. W. Cartrick.

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and East Grinstead, 1·41 in., the whole area including Littlehampton to Westerham. At Worthing, serious greenhouse damage from hail was reported to the Meteorological Office. At Balcombe the storm lasted from 1.30 to 3 a.m. To the north-west we get Claygate (9 : 9), 0·86 in.; Surbiton, 0·40 in.; Coombe, 0·97 in., with lower records more north, as Kingston 0·22 in. Probably distinct from this was the London area including Camden Square, the Strand (23 : + 9) 0·60 in., and Holborn, whence S. J. Richardson reported slight hail with torrential rain for 20 minutes between 3 and 4 a.m.

Considering next records along the axis prolongations, regressively no hail is recorded. This was true even so near as Ockley (– 3 : datum) and Capel (– 3 : – 1). Some fairly heavy rain records lie mainly just south-east of the axis as far back as Chichester (– 29 : – 2) 0·49 in.; Selham (– 20 : 1) 0·71 in.; Petworth (– 17½ : 1) 0·67 in., and, nearer the starting point, Oakwood (– 4 : – 1) 0·72 in. Four records nearer yet, but 2 to 4 miles to the north-west, range from 0·24 in. to 0·40 in.

At the north-east prolongation, beyond Bromley (23 miles), a continuation of heavy rain is indicated at Eltham (25½ : 1), 0·85 in., and Plumstead (28 : 1¼), 0·57 in. Stations more to the north-west had much less. At Greenwich (25 : 4) the hyetograph recorded only 0·10 in. from 2.25 to 2.40 a.m. out of a total of 0·19 in.

As already noted, further heavy splashes occurred across the Thames, but serious hail damage was only reported from Belhus, Aveley (34 : – 2), with slight damage at Romford (36 : 3), 0·26 in. At Belhus, Mr. W. Mills, gardener to Russell Lennard, Esq., reports holes in apples ½ in. deep, and other damage to fruit and crops. From Billericay (46 : – 1) to Chelmsford (50 : 2½) there are several records from 0·75 in. to 1·50 in., but mixed near the latter with much slighter falls, down to 0·09 in. A third splash occurred in the Tiptree-Kelvedon (62 : datum) district, falls ranging from 1·04 in. to 0·12 in., and a fourth near Colchester (70 : – 4) with one record of 0·55 in. From Ipswich (85 : – 3) to where the prolonged axis reaches the sea at Lowestoft (123 : datum) are a dozen near-by records, all under 0·25 in., and one about 3 miles north-west of Lowestoft of 0·28 in., whilst 0·08 in. only fell 2 miles further north-west.

Summarising these figures they indicate that the hail squall from Holmwood to Bromley was a special phase of the heavy thunderstorm which developed between south-west to south-east from Holmwood. Heavy rain fell along the south-west prolongation of the squall axis from Chichester on, but we have no knowledge of the time. It was only under Leith Hill that hail became a marked feature, and this continued to Bromley. Beyond there, along the axis, heavy rain fell more or less continuously to the Thames and then in 3 or 4 heavy splashes across Essex. Destructive hail accompanied the first splash just north of the Thames. Further on no hail has been reported, even among the heavy downpours around Billericay and Chelmsford. Beyond Colchester the axis lies 4 miles north-west of Ipswich, passing out to sea at Lowestoft, but in Suffolk the rainfall was moderate.

Time Records.—Except in the hail-squall area none have been received along or close to the storm axis, and there are only the following seven hyetograms from at all near :—

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Station.	Position by axis line.	Total fall (24 hours).	During the period.	Time a.m.	Remarks.
		in.	in.		
Calshot . .	−48 12	0·15	0·01	1.15-17	Rest earlier.
Wallington . .	14¾ 3¾	0·43	0·21	2.6-35	Total from 1.45 to 3.50.
S. Kensington .	20½ 10	0·33	0·28	2.40-46	Only approximations.
Hendon . .	23 17	0·13	0·08	2.35-40	0·04 earlier; 0·01 later.
Greenwich . .	25 4	0·14	0·10	2.25-40	Rest 3.10-12.
Felixstowe . .	87 − 13	0·18	0·12	4.20-30	Rest by 5.30.
Capel, Kent .	20 − 20	0·08	0·08	3.30	No other rain.

For the Calshot, Hendon, Felixstowe, and Capel records I am indebted to Capt. E. W. Barlow, R.A.F.

The Meteorological Office kindly sent a copy of all the records reporting thunderstorms for the 15th–16th, many of which also noted the times. But these evidently are as a rule only approximate guesses of rudely awakened observers, like most of the 190 sent to myself.

With two exceptions they are confined to the south-east, in which direction sheet lightning was recorded from Wiltshire (1.30-2.15 a.m.). Thunderstorms at Hemel Hempstead (2.30 a.m.), Rothamsted (4 a.m.), Hitchin (3 a.m.), and Cambridge (3 a.m.) indicate with the Wiltshire note a boundary line roughly parallel to and from 30 to 40 miles distant from the storm axis. Thus the area embraced all of Kent, Sussex, Surrey, Middlesex, Herts and Essex, with more or less of the adjoining counties. The times reported range from 1 a.m. at Grayshott, near Haslemere, to about 5 a.m. in N. Essex and Suffolk. No record south of the Thames is given later than 3 a.m. and, outside the London area, none north of it earlier.

The two other stations are near Craven Arms, Shropshire, at 3 a.m. (0·59 in.), and Huddersfield at 4.30 a.m. (0·66 in.), records which possibly represent a parallel line of storm 150 miles to the north-west and travelling at about 50 to 60 miles per hour. Numerous falls of 0·50 to 0·75 in. occurred in these parts.

Except these two large splashes a cursory examination of the Camden Square records, by the courtesy of Mr. Carle Salter, shows that no other heavy fall occurred away from the storm-axis, except a splash including Peterborough, March, and Wisbech (0·88 in.).

Selecting the more precise records from the whole area we find a general time drift from 1.15 on the Hampshire coast (Calshot) to 4.20 in S. Suffolk (Felixstowe), or a travel of 135 miles[1] in about 3 hours, giving 45 miles per hour.

Turning to the records within the devastated area, Table I. gives the more precise returns, again showing a marked progressive character. Of these 8 may be selected as being the most reliable (see next page).

Further on we unfortunately have no records sufficiently exact, 2.30 being frequently given up to Brigstock Road (18 miles).

Since the 5th and 6th records were both carefully checked, the mean value, omitting Buckland, of 36 miles an hour is perhaps not far from

[1] Measured from maps Nos. 25/6 and 27/8 Bartholomew's Citizen's Atlas, scale 1 inch to 10 miles. So most other measurements outside the special zone; these on 1 inch and 6 inch ordnance or other large-scale maps.

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Station.	Distance from datum.	Time.	Resulting velocity.
	miles.	a.m.	m.p.h.
Holmwood	1	1.55	...
Buckland	6	2.0	60
Cheasley	7¾	2.8	31
Chipstead	11	2.12	35
Purley, Skerryvore	14⅝	2.15	41
,, Asgarth	14¾	2.16	39
Beechwood Road, Sanderstead	15¾	2.20	35
Moreton Road, Croydon	16½	2.20	37
Mean velocity	...	...	40
Omitting Buckland	...	...	36
Or 25 minutes for the 15½ miles	...	...	37½

TABLE I.—Time Records of Hail Squall, July 16, 1918.

Stations within one mile of axis.	Position by storm axis.	Time of commencement.	Duration of hail.
		a.m.	mins.
Holmwood	1 0	1.55	10
Buckland	6 0	2.0	5
Cheasley	7¾ − ⅛	2.8	8
Eyhurst	10 + ⅛	2.15	10 to 15
Chipstead	11 + ¼	2.12	20
Cane Hill, Coulsdon	12⅓ + ½	2.10	7 to 10
Portnalls Road, Coulsdon	12⅝ + ⅝	2.20	10
Fairdene Road, ,,	12¾ + ¼	2.10	7
Chipstead Road, ,,	12¾ + ½	2.15	15
The Avenue, ,,	13 + ⅛	2.10	15
Hayes Lane, Kenley	14 − ⅛	2.5	10
Banstead Road, Purley	14½ + ⅝	2.12	11
Godstone Road, ,,	14⅜ − ⅛	2.15	12
Dale Road, ,,	14½ + ⅛	2.15	15
Cinder Path, ,,	14⅛ 0	2.17	10 to 11
Hall Road, ,,	14⅝ 0	2.15	11
Skerryvore, ,,	14½ − 1/16	2.15	11
Selcroft Road, ,,	14⅜ + ⅛	2.15	15
Asgarth, ,,	14¾ + ⅛	2.16	9
Beechwood Road, Sanderstead	15¾ + ¼	2.20	25
Moreton Road, Croydon	16½ + 1	2.20	5

Stations within 3 miles NW of axis (except Holborn).	Position by storm axis.	Time of commencement.	Duration of hail.
		a.m.	mins.
Walton-on-Hill	7½ + 2	2.15	15
Tadworth	9 + 1⅝	2.11	8
Kingswood	9½ + 2¼	2.10	20
Smitham Bottom Lane	13¾ + 1½	2.15	15 to 20
Alcester Road, Wallington	14⅜ + 3¼	2.25	5
Waddon Court Road, Croydon	16⅛ + 2⅛	2.15	15
Park Hill Road, Croydon	17 + 1½	2.30	20
Brigstock Road, ,,	18 + 2½	2.30	10
Norbury Crescent, ,,	18 + 3	about 2	¼ hr.
Holborn	23½ + 9	2 to 3	20

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the fact, though probably too low. Hence the progression is of the same order as the general advance of the thunderstorm area (45 miles) noted above in the 135 miles from Calshot to Felixstowe.

Greenwich (25 : 4) with time 2.25 a.m. gives the greater velocity of 48 miles. Calshot to Holmwood (– 49) gives the much higher velocity of 73 miles. But then it lies well west of the axis. Even the Wallington record, not 4 miles off, diverges considerably.

Meteorological Conditions as shown by recording instruments, mainly from records kindly submitted by the Meteorological Office.

TABLE II.—Upper Air Conditions. Wind over District from Pilot Balloon Ascents.

Height (Feet).	Wind Direction and Velocity in Miles per Hour.					
	Shoebury-ness.	Shoeburyness (Shell burst).	Grain.	Beachy Head.	Hendon.	Calshot.
July 15, 1918. Time.	16 h.	..	18 h. 15 m.	18 h.		
	Lost in stratus		Lost in st. and cu.	Lost in stratus		
7000	...	...	SW 29	...		
6000	...	...	SW 27	...		
5000	SW'S 22	...	SW'S 24	...		
4000	SW 21	...	SW'S 23	SW'S 20		
3000	SW'S 20	...	SW'S 15	SSW 19		
2000	SW'S 15	...	SSW 14	S 18		
1000	SSW 18	...	SSW 17	SE 13		
Surface	...	...	S 13	SE'S 8		
July 16, 1918. Time.	6 h.	9 h. 45 m.	7 h.	7 h.	7 h.	7 h.
	Lost in st.-cu.		Lost in st.-cu.	Lost in st.	Lost in nb.	Lost in st.-cu.
16000	...	SW 56				
13000	...	SW'W 50				
10000	...	SW'W 48				
6000	SW'S 33	SW 33				
5000	SW 29	...	SW'S 28	SW'S 27		
4000	SW'S 22	...	SW'S 28	SW 22		
3000	SW'S 21	...	SW'S 20	SW 21		
2000	SW'S 22	...	SSW 28	SW'S 15	...	SW'W 18
1000	S'W 20	...	S'W 17	SW'W 12	SW 6	SW'W 14
Surface	...	...	SW'S 1	WSW 8	SW'S 2	SSW 8

Temperature.—My own thermograph at *Asgarth*, Purley, at 2.16 a.m. stood at 62°·5 and dropped suddenly 3° only, rising gradually again to 62°·5 by 6 a.m. The *Wallington*[1] record stood at 61° at midnight, dropped sharply 0°·5 at 1.45 a.m., gradually falling 1° more by 3.45. The maxima were 67° on the 15th (1 p.m.) and 72° on the 16th (11 a.m.).

The *Wallington Barograph* had been slowly falling from 29·98 ins. at noon to 29·90 ins. at midnight, with the following records during the critical period:

1.45 a.m.	29·865 ins.
2.0 „	29·875 „
2.40 „	29·865 „
2.45 „	29·875 „

[1] These were kindly supplied by F. C. Bayard, Esq.

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At *Greenwich* the *Wind direction* was SE up to 2.50 a.m., swinging to NW by 3.5; steady there to 3.20, when it returned to SE. (Compare values at Asgarth given earlier—10 p.m. S; 11 p.m. SE, stronger; 2.15 a.m. SSW; 2.30 a.m. SE.)

Wind Pressure, which had been almost negligible, rose to 1·2 lbs. per sq. foot at 2.25 a.m.

At *South Kensington* the *mercurial barograph* at 2.45 a.m. shows a slight wave and V-shaped rise and fall. The micro-barograph was very steady to 0.45 a.m., irregular oscillations following up to 2.30 a.m., when a marked trough appears, followed by a second, still sharper, having a drop of 2 mm., the apex at 2.45 a.m. After this V followed a sharp rise (4 mm. in all) about 2.46 a.m., a drop of 7 mm. immediately following at 2·54, with an equally sharp rise of 3 mm., followed by slight oscillations (15 mm. = 1 millibar, therefore the drop was ½ mb.).

The Pressure Anemometer for the 24 hours had rarely recorded over 5 metres per sec., 7 m./s. occurring at 3.40 p.m. It gradually settled to 2 m./s. by 10.40 p.m. At 2.45 a.m. came a sudden rise, up to 7 m./s. (15 miles per hour), at 2.50 a.m. falling back in 10 mins. to 1½ m./s., with another gust at 3.5 a.m. of 4 m./s., afterwards gradually settling to 1 m./s.

The *Thermograph* touched 295·1a. at 2.40 p.m. on the 15th, whence it slowly fell to 290·9 at 2.40 a.m. on the 16th, and sharply to 290.2 at 3 a.m., rising by 3.30 a.m. to 290·5 (290a. = 62½° F., nearly).

The Meteorological Office has further kindly supplied *Upper Air Records.*

Upper Air Temperatures at Martlesham Heath, near Woodbridge, Suffolk, at 8 a.m. fell from 291·3a. at surface to 283·0 at 8000 feet, and 264·1 at 16,000 feet, or 8·3a. and 18·9a. respectively, giving for the latter an adiabatic mean gradient. The greatest falls were 5a. from 4/6000 feet, 6·1a. from 8/10,000 feet, 5a. from 14/16,000 feet. The fall was only 0·3 up to 2000 feet and 1·1 from 6/8000 feet. These facts are noted as possibly of some significance, as may also be the change in wind-twist from Westerly before to Easterly after the passage of thunderstorm conditions.

Table III. shows the rain records received. It will be noted that the rain rates along the axis were excessive, culminating in that at Skerryvore, Purley, of at least six inches per hour, over a space of 11 minutes. Where heavy hail fell probably 20 to 25 per cent should be added in the case of open funnel gauges.

Other similar Hail Squalls.—The only more destructive storm in recent years was that in Essex, 24/6/1897, because of the violence of the wind, a phase entirely absent in the present storm.[1] Here also the worst damage was in a mile-wide strip from WSW to ENE. The total damage was estimated at £200,000 in a 37-mile stretch, 8 to 10 miles wide. The rate of travel was 30 m.p.h. The present storm probably did damage up to £10,000 in a 19-mile stretch ½ mile wide.

The Essex report refers to previous visitations in that county in 1872, 1824 and 1565, all in July.

As noted already, the last local hail records are from Bromley and Beckenham, which suffered so severely in June 1914.[2] But this was

[1] Cf. *Essex Naturalist*, **10**, 1897, pp. 112–129. [2] *Beckenham Journal*, June 20, 1914.

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not a travelling storm; nor was that at Richmond, Yorkshire, on July 8, 1893 (*Nat. Hist. Journal*), when corrugated iron sheets were pierced.

The more noteworthy points of the present storm may be summarised as follows:

(1) The hailfall appeared to be an episode of an otherwise normal nocturnal thunderstorm. Other similar visitations seem to have been all in the daytime.

(2) The narrowness of the track and almost unvarying direction, south-west to north-east.

(3) The almost unprecedented size of the larger stones and their irregular, jagged surface.

(4) The sudden development of the storm cloud into an incessant electric display associated with the hailfall and almost equally sudden cessation after nine to twelve minutes.

TABLE III.—Rainfall Records in or near Hail-Squall Area, July 15–16, 1918.

I. Stations within 1 mile NW or ½ mile SE of datum axis.	Distance along datum line and NW (+) or SE (−) of it.	Rainfall
		in.
Brockham	4 + ¾	0·96
Cheasley	7¾ − ½	0·60
Gatton Park	9½ − ¼	0·42
Eyhurst	9⅞ + ½	1·07
Chipstead	11 + ⅛	*1·10
,,	11⅜ + ½	0·98
Purley, Downscourt Rd.	14⅛ + ⅝	*1·14
,, Waterworks	14⅛ + ½	*0·96
,, Oakwood Ave.	14⅝ − 1/16	1·34
,, Riddlesdown Rd.	14¾ + ¼	1·03
Sanderstead	15¾ + ¼	0·85
Croyden, Avondale Rd.	15⅝ + ⅞	0·67
,, Shirley Hills.	17⅛ datum	0·79
Bromley	21½ ,,	1·28
,,	21¾ − ¼	0·82
,,	22 − ½	1·25
II. Stations over 1 mile NW from datum axis.		
Dorking	2⅛ + 2¼	0·25
,, Rose Hill	2⅜ + 1¾	0·47
Pixham	4 + 2	0·46
Headley	6⅞ + 2½	0·62
Ashstead	7 + 5¼	0·25
Walton, Hurst	7⅛ + 3	0·53
Walton-on-Hill	7⅛ + 2	0·53
Epsom, Durdans	9 + 4½	0·23
Burgh Heath, Can Hatch	9½ + 1½	0·66
,, W. Wks.	9⅝ + 2¼	0·50
Banstead, Court Ho.	11⅛ + 2¼	0·36
,, Asylum	12 + 2⅝	0·57
Malden	12½ + 8	0·15
Sutton	13½ + 4¾	0·22
,, W. Wks.	13¾ + 6	0·25
Wallington	14⅜ + 3¾	0·41
Wandsworth Common	14⅜ + 8½	0·29
Beddington	15¼ + 3⅛	0·34

II. Stations over 1 mile NW from datum axis (*cont.*).	Distance along datum line and NW (+) or SE (−) of it.	Rainfall
		in.
Wimbledon, Trinity Rd.	15¾ + 8½	0·39
,, Downs	16 + 10½	0·29
,, Sewage Wks.	16 + 8½	0·31
Waddon	16⅛ + 3⅜	0·38
Woodside	18½ + 1½	0·68
S. Norwood	18½ + 2½	0·32
,,	19⅛ + 2⅝	0·25
Anerley	19¼ + 2¾	0·35
Beckenham	20½ + 1½	0·78
Forest Hill	21¾ + 3½	0·21
Lewisham	23 + 2⅛	0·31
III. Stations along prolongation of axis to SW.		
Chichester	− 29 − 2½	0·49
Selham	− 20 + 1½	0·71
Petworth	− 17½ − 1	0·67
Haslemere	− 16 + 7½	0·28
Frensham	− 15 + 13	0·58
Hambledon	− 11 + 7	0·27
Godalming	− 8 + 8½	0·28
Hascombe	− 8 + 4	0·32
Ewhurst	− 4½ + 2	0·35
,, Coneyhurst	− 4½ + 3	0·24
Oakwood	− 4 − 1	0·72
Holmbury St. Mary	− 2 + 2½	0·40
Abinger	− 0½ + 4	0·35
IV. Esher Group.		
Claygate	8½ + 9	0·86
Esher	8½ + 10½	0·09
W. Molesey	9½ + 12½	0·03
E. ,,	10⅛ + 10⅝	0·08
Surbiton	10⅓ + 9¼	0·40
Kingston, County Hall	12 + 10	0·23
,, Sewage Wks.	12½ + 8½	0·15

* Old gauge reading, 25 % added. Hail smashed measure glass at Downscourt Road.

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TABLE III. (*continued*).

V. Stations from ½ mile to 5 miles to SE of datum axis.	Distance along and to SE of the datum axis.		Rainfall
			in.
Hartwood, Buckland	5⅛	2½	0·10
Reigate	6⅝	1⅜	0·25
,,	7¼	1⅜	0·21
,,	7⅛	1⅜	0·10
,,	7¾	1¾	0·16
Redhill, Warwick Rd.	8	2⅛	0·10
,, Station Rd.	8	2½	0·07
South Nutfield	8	4⅜	0·14
Nutfield Priory	8⅜	3½	0·07
Netherne Asylum	11½	⅜	0·29
Caterham ,,	12⅛	2⅛	0·07
,, Reservoir	12⅜	3⅜	0·07
,, Valley	13	3¼	0·09
,, ,,	13	3⅜	0·10
Kenley, Water Wks.	14½	⅝	0·56
Warlingham	15	2⅝	0·07
,, Pump. St.	15⅛	2½	0·07
Woldingham	15½	4	0·15
Farley Asylum	16½	2⅞	0·08
Feather Bed Lane, P. St.	17⅛	1⅜	0·09
Wickham Court	19⅛	1½	0·11
Downe	19½	4⅝	0·33
Keston	20	2⅜	0·08
Hayes	20½	1½	0·10
Bromley Common	21½	1½	0·08
,, ,,	22⅝	⅝	0·28
,, ,,	22½	1½	0·16
Orpington	22½	4½	0·34
Chiselhurst	23⅜	1⅜	0·07

VI. Records near axis up to R. Thames, within 4 miles.	Distance along and to SE of the datum axis.		Rainfall
			in.
Lewisham	+23	+2⅝	0·31
Eltham	+25	+1	0·85
Greenwich	+25	+4	0·19
Plumstead	+28	+1½	0·57
Dartford	+29½	−4	0·27
VII. Group around Cuckfield from Selsey to Forest Row. Distances from axis all − (to SE).			
Selsey	−36	−7	0·28
Felpham	−29	−9	0·12
Littlehampton	−24	−12	0·71
Wykehurst Park	−5	−12	1·47
Cuckfield, Hillfield Ho.	−2	−14	1·50
,, Henmead Hall	−2	−14	1·45
Haywards Heath		...	0·87
Balcombe, Water Wks.		...	0·63
,, The Gables	+2	−11	1·31
,, Stockcroft		...	1·13
Ardingly, Lynwood Ho.	+3	−14	1·46
,, Brook Ho.		...	1·57
Crawley Downs		...	0·54
Worth Lodge		...	0·29
,, S. Hill		...	0·65
Birchgrove		...	0·60
Horley	+5	−6	0·16
Lindfield, Gravetye	+5	−12	0·96
Wych Cross		...	0·62
Forest Row		..	1·09
E. Grinstead, Brockhurst Obs.	+7	−13	1·41
E. Grinstead, Highfields		...	1·32
Holly Hill		...	0·59

(5) The remarkable absence, before, during and afterwards, of any considerable wind.

(6) And yet the speed of translation, thirty-five to forty miles per hour, was that of a gale.

(7) The wind direction at Asgarth, Purley, was SSW or S by W, thus diverging from the storm axis, which tallied closely with that of the Essex storm and various wind-rush records.

(8) Unlike these latter or tornado squalls, it was practically unaccompanied by change in temperature.

(9) The cloud ribbon drifted eastwards or south-eastwards after the deluge, yet outside the very sharply defined south-east edge, the rainfall was almost negligible. The records probably consisted mainly of the precipitation a little earlier and later, but there are no hyetograms on this side to verify this point, except Capel (20 : − 20).

(10) The rapid reduction from the south-east edge in the hail volume and violence, though the accompanying warm rain apparently maintained the same volume over a width of at least a mile. The worst damage lay within a quarter-mile strip, except about and beyond Cane Hill and in a mile-long

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tongue due north at Purley. Elsewhere damage more than half a mile from this margin was slight.

(11) The uselessness in such storms of the old form of rain-gauge. At Asgarth, Purley, this recorded only 0·81 in. in all, against 1·03 in. in the Snowdon gauge, side by side.

(12) Such returns of recording instruments and upper air ascents as could be collected are given, in the hope that they may possibly lead in more capable hands to some elucidation of the acting cause.

In conclusion I must thank most warmly the many kind contributors of the data here used, especially the many records received from the pupils of the Whitgift Boys' School and the Girls' High School, Croydon, and the Boys' Secondary County School, Kenley.

DISCUSSION.

The President (Mr. R. H. Hooker) said that Mr. Clark had brought a most interesting paper before the Society. The causes of these storms were somewhat obscure, and he hoped the very heavy work done by Mr. Clark might serve to throw some light on them.

Mr. F. J. Gurney said he had some experience of hailstorms, and the worst he remembered was one in which the wind broke and carried into the air a cart hovel under which some men were sheltering two miles away from where the hail fell.

Mr. R. G. K. Lempfert said that in the course of the history of the Society they had had many papers on storms—sometimes wind squalls, sometimes hail—which followed a straight line, and he wondered whether they had any connection with line squall phenomena and might be regarded as local exaggerations of intensity at one point in the line front. He called to mind the case of the tornado or whirlwind which did great damage in the industrial districts of South Wales in October 1913. On that occasion there was evidence of line squall phenomena having occurred on the western side of the tornado line. The line along which the tornado swept apparently marked the eastern boundary of the line squall phenomenon. On the western side there was very copious rainfall, on the eastern side there was very light rain and no suggestion of a line squall.

Captain C. K. M. Douglas said that in France there were equally severe thunderstorms and some hail on that night. The track was practically parallel with the Surrey storm. There seemed to be a slight squall with the storm which caused a temporary fall of temperature and rise of pressure, but after the storm passed the temperature rose again. The fact that the storm did occur on a parallel belt suggested that the upper air conditions might have been favourable over a fairly wide area. On the evening before, there was a very high humidity between 4000 and 10,000 feet. There must have been violent upward currents above the freezing-point level of 12,000 feet to have formed such large hail. Mr. W. Crofts in his report of the storm said the storm travelled "round by east toward London and approached Holmwood from north-east." With the upper current prevailing that would have been impossible. What the observer saw was probably a new storm developing behind the old one.

Mr. J. Fairgrieve said he would like to emphasise the extraordinary advantage of obtaining observations of this kind from school children. Referring

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to the knobbliness of the hailstones he suggested there was evidence of crystallisation in the upper air and the knobbles were the stumps of the crystals shot out from the ice. With regard to the linear arrangement of the storm he said that next day there was a striking sequence of thunderstorms and thunderstorm rain in five separate belts over Britain almost exactly parallel to the belt of hail. At the end of the paper the upper air velocities were given, and showed that the wind rose, at the most, to 25 miles an hour. Under such conditions he thought there could be no possibility of a line squall. It must have been a development along a line and not a front that moved in any kind of way. He had plotted the times at which the hail fell, and it seemed to him that there was a little evidence that at one time there was something in the nature of a drift northward and a propagation along a line at a very much greater rate surging forward. He believed that streaks of air of different humidity and temperature from two different sources of supply and coming into juxtaposition were probably at the bottom of the storm.

Major A. MACDONALD, R.A.M.C., referred to the linear rainfall types experienced in Jamaica.

Mr. J. E. CLARK said the points of peculiar importance about the storm were that there was no change of temperature to speak of, no great wind, and that the margin on one side was so absolute that there was no heavy rainfall even a few hundred yards away from the sharply marked cessation of hailfall.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

March 17, 1920.

Ordinary Meeting.

Mr. R. H. HOOKER, M.A., President, in the Chair.

JOSEPH BELL, 16 Flemington Street, Flemington, Motherwell, N.B.;
JOHN EMERSON COWPER, Meteorological Office, South Kensington, S.W.7;
Captain ARTHUR WILLIAM DARBY-LEGGE, 30 Queen Street, Hammersmith, W.6;
ERNEST FREDERICK HARRISON, 25 Oxford Street, W.1;
WILLIAM HOLMES, 22 Arundel Mansions, Kelvedon Road, Fulham, S.W.6;
J. STEWART PETTIGREW, 170 Hope Street, Glasgow;
ROBERT HUDSON ROUTLEDGE, Northaw Place, Potters Bar, Herts;
FREDERICK WILLIAM SMALLSHAW, 308 Hucknall Road, Nottingham;
HAROLD SMITH, Waverley, Warminster Road, Sheffield;
NORMAN HAROLD SMITH, 4 Elthorne Park Road, Hanwell, W.7;
Squadron-Leader JOHN SOWREY, R.A.F., Yeoveney, nr. Staines, Middlesex;
MAGNUS THORFINN SPENCE, B.Sc., 8^2 Clydesdale Mansions, Notting Hill, W.11;
Lieut. GORDON CHARLES STEELE, V.C., R.N., "Ixelles," Hythe, Kent;
Major TREVOR FREDERICK GEORGE STRUBELL, 25 Addison Court Gardens West Kensington, W.14;
JOHN WADSWORTH, B.A., 4 Moorgate Street, E.C.2; and
PERCY G. WILLSON, 20 Garlies Road, Forest Hill, S.E.23,

were balloted for and elected Fellows of the Society.

Captain C. K. M. DOUGLAS, F.R.Met.Soc., delivered a Lecture on "CLOUDS AS SEEN FROM AN AEROPLANE" (p. 233).

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April 21, 1920.

Ordinary Meeting.

Mr. R. H. HOOKER, M.A., President, in the Chair.

RUPERT FORBES-BENTLEY, Marslands, Beckley, Sussex ;

GEORGE RUDD COLLINSON, B.Sc., Assoc.M.Inst.C.E., Water Engineer's Office, Guildhall, Swansea ;

CLAUDE WALTER DEAN, The Retreat, Flackwell Heath, nr. High Wycombe, Bucks ;

Lieut. STANLEY FIELDER, O.B.E., R.N.R., 64 Great King Street, Edinburgh ;

JOHN HAMMOND, 50 Cardiff Street, Sheffield ;

FRANCIS ERIC LEE, The Villa, Tetchill, nr. Ellesmere, Shropshire ;

Miss WINIFRED ANNIE QUENNELL, 38 Minford Gardens, West Kensington, W.14 ;

JOSEPH HENRY ROBERTS, Dacre Bank, Oakwood Road, Rotherham ; and

WALTER CHARLES WAUGH, 24 Rushbrook Crescent, Walthamstow, E.17,

were balloted for and elected Fellows of the Society.

The following communications were read :

1. "ROYAL OBSERVATORY, GREENWICH : POLAR NIGHT-SKY RECORDER" (p. 243).

2. "LOCAL WEATHER CONDITIONS AT MULLION, CORNWALL." By Lieut. N. L. SILVESTER, R.N.V.R., F.R.Met.Soc. (p. 245).

3. "THE SURREY HAILSTORM OF JULY 16, 1918." By J. EDMUND CLARK, B.Sc., F.R.Met.Soc. (p. 271).

CORRESPONDENCE AND NOTES.

Distribution of Relative Humidity over Nigeria.

The sources of the data are the Nigerian Government *Gazettes* and *Blue Books*, as in the case of temperature ; relative humidity is given, but not the dry and wet bulb readings. The stations are for the most part the same as before (see Table I., p. 206, April 1920, for co-ordinates and height, and Fig. 1, p. 205, for positions of stations). The observations were taken at 9 a.m. at all stations. Unfortunately, in the case of the Southern Province, the figures at many stations from time to time became unreliable, and some stations had to be abandoned altogether. The remainder were subjected to a severe scrutiny. First, any monthly mean which departed widely from the figures for the same month in other years was weighed by comparison with neighbouring stations, and by considering it in connection with the corresponding temperature and rainfall. If it appeared erroneous, it was forthwith rejected. Monthly averages were then computed from the survivors, and these were plotted on squared paper, neighbouring stations being kept together. Through these points smooth curves were drawn by hand, and from these curves the final values given in Table I. were taken. The comparison of neighbouring stations showed that some anomalies, such as the slight rise in December and January in the northernmost stations, are real.

The figures so obtained were plotted and fitted reasonably well into systems of isopleths. Of these maps, those for January, April, July, October, and the Year are reproduced, together with a map showing the range from the driest to the wettest month.

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TABLE I.—Mean Values of Relative Humidity at 9 A.M. in Nigeria.

Stations and Period of Observation.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	%	%	%	%	%	%	%	%	%	%	%	%	%
Sokoto, 1907–1918	29	26	28	37	47	57	67	74	70	51	32	31	46
Birnin Kebbi {1907	30	28	32	40	50	61	72	76	69	54	36	36	49
Birnin Kebbi {1913–1915													
Kano, 1907–1918	34	30	31	40	50	61	71	76	70	50	35	34	49
Katagum, 10 yrs., 1907–1918	35	30	27	35	46	56	68	75	69	45	34	36	46
Geidam, 1907–1913	33	28	26	30	39	50	63	75	67	38	27	33	42
Maiduguri, 1907–1918	38	36	32	40	49	59	71	79	73	50	42	40	51
Nafada, 5 yrs., 1913–1918	41	35	29	40	51	62	70	75	72	59	49	43	52
Zaria, 1907–1918	33	29	37	50	63	74	77	78	73	62	42	35	54
Kaduna, 1913–1918	39	36	46	59	69	78	82	84	81	70	45	35	60
Kontagora, 7 yrs., 1907–1914	28	31	43	55	65	75	81	81	78	69	41	30	56
Zungeru, 1907–1918	42	44	55	67	74	79	83	85	84	78	60	44	66
Naraguta, 1913–1918	33	30	39	53	62	68	75	80	70	55	39	32	53
Bauchi, 9 yrs., 1907–1918	34	26	30	44	55	65	73	77	72	55	35	33	50
Yola, 1907–1918	45	45	48	58	66	75	78	77	77	72	55	44	62
Womba, 10 yrs., 1907–1918	46	49	55	65	73	77	80	82	82	76	60	44	66
Jebba, 1913–1916	44	46	53	61	69	75	76	73	79	75	63	47	63
Ilorin, 1907–1918	63	65	68	72	77	80	81	79	83	81	74	64	74
Ogbomosho, 1912–1918	66	70	76	81	84	87	88	85	89	87	80	71	80
Offa, 1913–1918	59	67	74	77	79	80	81	81	82	80	77	69	75
Oyo, 1911–1918	71	72	74	77	80	84	89	91	91	88	83	73	81
Baro, 1913–1916	53	49	53	59	68	73	69	67	73	70	64	58	63
Lokoja, 1907–1918	67	65	64	69	73	76	78	78	79	76	72	69	72
Ibi, 1913–1918	48	47	57	66	72	77	80	82	82	77	69	55	68
Obudu, 1913–1918	59	63	70	79	85	87	87	85	85	84	81	69	78
Ankpa, 4 yrs., 1913–1918	62	64	70	75	80	83	83	84	85	80	70	60	75
Okwoga, 1911–1918	58	62	68	72	76	79	82	82	83	79	71	59	73
Ondo, 1911–1918	78	77	78	80	83	86	88	88	87	84	82	80	83
Olokemeji, 1911–1918	82	81	82	84	87	89	88	89	87	86	84	83	85
Abeokuta, 1911–1918	83	81	82	83	84	85	86	86	87	85	84	83	84
Epe, 1911–1918	85	80	79	78	80	82	85	86	84	82	80	82	82
Yaba, 1913–1918	81	77	74	76	79	83	85	83	83	80	82	83	81
Ebute Metta, 1911–1918	80	81	82	79	78	82	82	81	80	80	79	78	80
Agege, 1915–1918	87	82	81	84	88	90	88	85	83	83	84	85	85
Lagos, 1891–1901, 1914–1918	82	82	78	78	80	86	85	84	83	82	82	83	82
Benin, 5 yrs., 1912–1918	81	80	81	82	83	85	85	84	85	85	83	82	83
Agbor, 5 yrs., 1913–1918	87	86	85	86	87	88	89	88	89	88	88	87	87
Warri, 1911–1918	87	88	88	87	86	86	87	87	87	86	85	86	87
Asaba, 1890, 1912–1918	71	73	76	78	81	82	83	83	84	83	82	79	80
Onitsha, 1911–1918	79	80	82	84	85	87	89	89	87	86	84	81	84
Owerri, 1911–1918	72	73	75	78	80	82	83	82	83	82	78	73	78
Enugu Ngwo, 1916–1918	71	69	68	69	71	74	77	80	82	79	75	72	74
Abakakali, 1913–1918	66	69	72	75	79	82	84	84	87	85	78	66	77
Afikpo, 1911–1918	79	80	80	78	77	80	83	85	85	83	81	80	81
Ikom, 5 yrs., 1911–1918	81	81	79	79	81	83	85	88	87	84	82	81	83
Ikot Ekpene, 7 yrs., 1911–1918	77	79	80	79	80	84	87	86	85	86	83	80	82
Calabar, 1911–1918	82	82	82	82	83	85	87	86	84	84	84	82	84
Opobo, 1911–1918	82	83	83	83	84	86	87	87	86	86	83	82	84
Bonny, 1911–1918	81	82	82	82	82	84	86	84	82	84	83	82	83
Degema, 1911–1918	79	80	80	81	82	83	85	85	84	85	81	79	82
Brass, 1911–1918	75	74	75	74	79	83	85	83	84	80	75	74	78
Akassa, 1911–1914	77	78	78	77	79	82	83	82	84	83	78	77	80
Sapele, 1911–1918	84	84	83	80	83	87	88	86	86	83	82	84	84
Forcados, 1911–1918	80	78	79	80	81	83	85	85	85	83	79	80	81
Lagos, 8 h.	87	87	82	81	84	87	86	84	85	87	86	87	85
,, 16 h.	73	74	72	73	75	79	80	78	79	79	75	74	76
Difference	14	13	10	8	9	8	6	6	6	8	11	13	9
Asaba, 1890, 9 h.	81	86	86	85	85	87	89	85	88	86	83	85	85
,, 21 h.	76	82	88	87	90	93	94	90	96	90	90	89	89

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Areas with humidity below 30 per cent occur in the north in November and from January to March, with a maximum extent in February. In August the 70 per cent line disappears from the map, and only the extreme north of the colony lies below 75 per cent. The most rapid decrease is from September (Geidam 67 per cent) to October (Geidam 38 per cent). Thus in the north there are two minima, February and November, a chief maximum in August,

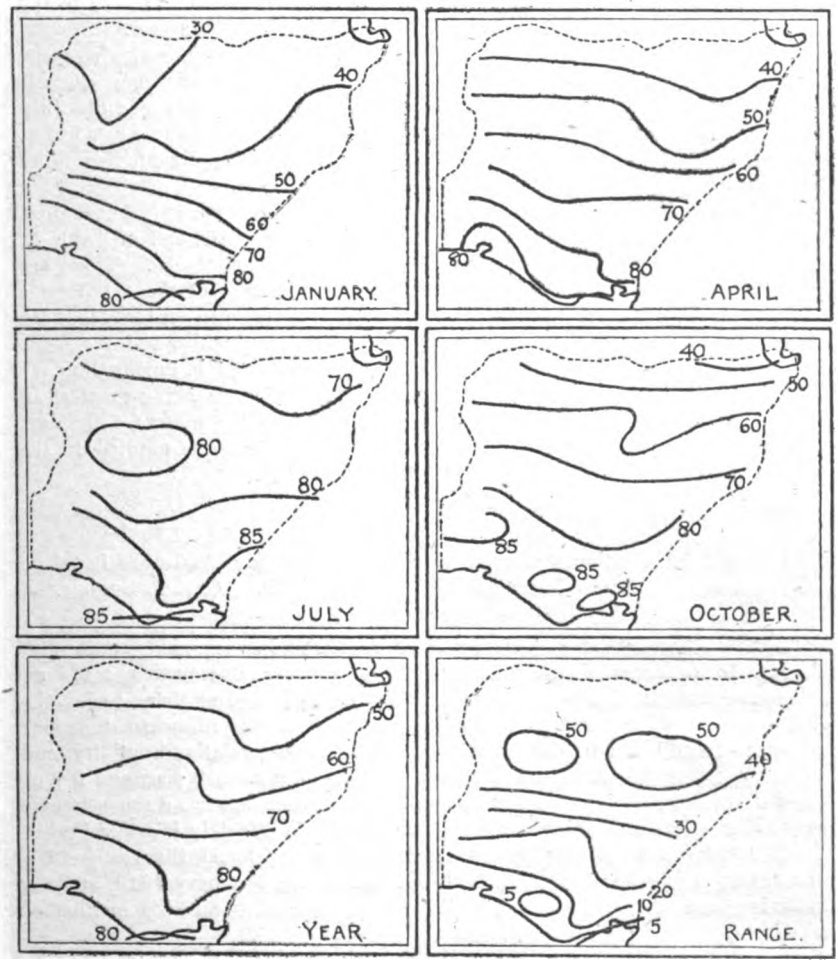

FIG. 1.—Percentage of Relative Humidity at 9 h.

and a slight secondary maximum in December. This latter, though real at 9 a.m., would probably disappear if it were possible to take the mean for the day, as 9 a.m. is much nearer sunrise in that month than in November and February. August, of course, is the centre of the rainy season in the Northern Province.

In the south the annual range is much less, and the isopleth for 80 per cent is never absent from the coastal and delta region. It is noteworthy that the southernmost portion of the Niger delta is drier than the plain further

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north, Brass having a mean of only 78 per cent. From June to October the line for 85 per cent appears, and includes its maximum area in July.

The map for the Year shows a steady increase from just over 40 per cent in the extreme north to above 80 per cent on the coastal plain. In the Niger valley the isopleths bend southwards, towards the relatively dry area near the mouth of the delta, already referred to. There is also a tendency for the humidity to be less in the river valleys further north, especially the Niger valley near Jebba, but this is only brought out in the wet season, being masked by the steep gradient from south to north during the remainder of the year.

The greatest annual range curiously is not in the far north, where the humidity is least in January, but further south in the plateau region where it exceeds 50 per cent (Kontagora 53 per cent, January 28 per cent, July 81 per cent). The least annual range also is not met with on the coast, but at a short distance inland, falling below 5 per cent (Warri 3 per cent, November 85 per cent, February and March 88 per cent).

Very few data are available for determining the daily range, but figures for a few years at Lagos for 8 h. and 16 h. are given at the end of Table I., with those for a single year (1890) at 9 h. and 21 h. at Asaba. These are interesting. Lagos shows an average excess of 9 per cent of the 8 h. figures above those for 16 h., with an annual variation from 14 per cent in January (middle of the dry season) to 6 per cent from July to September (rainy season). At Asaba the humidity at 9 h. is greater than that at 21 h. during January and February, but less in the other months, the difference being greatest in September (8 per cent). If we adopt $\frac{1}{2}$ (9 + 21 h.) as the mean for the day, we have the following (smoothed) corrections at Asaba to be applied to the 9 h. observations to reduce them to the mean of the day:

J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Y.
−1	−1	0	+1	+2	+3	+3	+3	+3	+3	+3	+1	+2

It should be mentioned that these data for Lagos and Asaba are based on daily figures in manuscript and can be taken as reliable. C. E. P. Brooks.

Analysis of the Winds at Sydney, New South Wales.

Mr. D. J. Mares of the Commonwealth Weather Bureau has made an exhaustive examination of the winds of Sydney, classifying them under the eight points of the compass, and grouping them according to the four seasons. In addition he has averaged the temperature, relative humidity, and water content of the various winds for the hours of 9 a.m., 3 p.m., and 9 p.m. based on the observations for the 10 years 1903–1912, and has discussed these very fully in an interesting article in the *Australian Monthly Weather Review*, April 1912 (published 1919). He has further developed the study in a subsequent article in the *Education Gazette* (Australia), February 1919, and the following extract relating to the South wind will illustrate his method of treatment.

"Southerly Burster.—As a relief to the high temperatures attending the 'nor'-wester' comes that sudden gust from the south known as a 'burster.'

"Both as regards duration and velocity, this is pre-eminently a summer wind. Following the greatest heat in a summer day, and often when the temperature is well in the hundreds (°F.), this cool breeze works up from the southward and acts as a welcome compensation for the preceding trying conditions. It is usually heralded by clouds of dust, which soon obscure the horizon, and at times, for a short period, has but little appreciable effect on the temperature. But when it sets in definitely, a fall of as much as 20° F. has been noted in a few minutes. Rain very rarely accompanies these 'bursters.'

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"The greatest velocity ever recorded from the south was 79 miles per hour in July 1887. These winds occur almost wholly during the warmer months of the year, but an isolated one or two may be experienced in the colder periods. As a general rule they last no longer than four or five hours in the summer, whilst the southerlies of the winter blow for only half as long on the average.

"In December the average duration from the south is 4·3 hours per day, and the total mileage, 56·6; in January, duration 4·5 hours, and mileage 63; and in February, duration 4·5 hours, and mileage, 58. The occurrence of a southerly 'burster' almost invariably depends on the passage east of an inverted V depression, shaped thus Λ. The depression governs at first the hot North-west breeze, and later, after a partial calm, the sudden Southerly gusts from which the 'burster' gains its name."

Mr. Mares states that he has found his method of grouping the winds of much use in his practical work as State Meteorologist of New South Wales both in satisfying the requests of business people and in substantiating some of the theories of meteorology with regard to relative dryness or dampness of the winds considered from the view-point of their origin.

In connection with this discussion of the winds of Sydney, Mr. Mares has prepared an ingenious diagram in which all the details mentioned above, and the duration, rate of fall per hour, and amount of rainfall, together with mean wind velocity and number of gales, are set out under each direction. In the centre is a graph showing the average amount of rainfall during each hour of the day. This diagram shows very readily the characteristics of the climate of Sydney in a remarkably clear manner. The data for the wind velocity refer to 37 years' observations.

Sun-Flash Balloons for Continuous Signalling.

PROBLEM: To measure an angle between two surfaces carried by a balloon, when the latter shows as a mere dot in the field of view of the theodolite.

It is hoped that the angle between the two surfaces can be made to depend upon the temperature, humidity, or other characteristic of the air through which the balloon is passing, and if the problem can satisfactorily be solved a ready means of obtaining upper air data by means of non-registering balloons will thus be made available.

A solution of the problem has been sought by observing the intervals of time between flashes of sunlight reflected by polished surfaces carried by the balloon and rotating with it.

Experiment I.—In order to get flashes in spite of the varying elevations of the sun and balloon, the reflectors were made portions of cylinders having horizontal axes. The radius of the cylinder was 10 cm. Two such cylindrical pieces of thin aluminium sheet, each measuring 11 × 8 cm., were fixed so that their horizontal straight sections made an angle of 47° with each other. The concave surfaces were painted black. The system was sent up on a 90-inch balloon, which, according to its weight and lift, ascended 142 metres per minute. Unfortunately no parachute ("parascent") or other steadying device was used, and the balloon rolled about through an angle of ± 30°, tilting the cylindrical axes with it, so that in the first 600 metres no readings were obtained. After that it became rather steadier and we got the following by using a stop-watch ticking 50 times a second. The time of complete revolution varied to and fro between 2·1 and 2·4 seconds. The angle to be measured came out 75°, 103°, 63°, 57°, 53°, 99°, mean 75°, instead of 47° as expected. The greatest height at which the angle was measured was 2·8 k.

Experiment II.—To diminish the rolling, the reflectors were attached to a

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frame of hemlock, which was controlled in direction by a string hanging from the balloon and ending in an inverted parachute. The time of rotation varied irregularly between 5·04 and 4·49 seconds. The angle to be measured came out 33°, 21°, 20°, 8°, 42°, 4°, the mean of which is 21°, agreeing exactly with the value found by protractor and straight-edge. But there were also a number of observed intervals between flashes which were not satisfactorily explained. One reason for this is that the flash from the concave sides of the reflector was not entirely abolished by the Indian ink, with which it was covered.

Prospect.—The directions in which greater accuracy is to be sought are probably: (i.) Complete obscuration of the back of the reflectors. (ii.) Still less rolling. (iii.) A longer period of rotation so that the observer's reaction time may matter less. One of our "cracker balloons" rotated once in every 6 seconds. Why balloons should rotate at all is rather a mystery, seeing how nearly symmetrical they are. (iv.) A record of the time of *every* flash, so that irregular variations of the speed of rotation would be of small importance. This could be obtained by means of a chronograph recording on a paper strip. As the observer's hands are occupied with the azimuth and elevation adjustments, the chronograph key might suitably be operated by the lips, as is done in psychological laboratories.

LEWIS F. RICHARDSON.

BENSON OBSERVATORY,
June 1, 1920.

Cloud Amount in Brazil and Chile.

During recent years marked progress has been made by some of the South American meteorological services whose data as now published are much more complete and uniform than formerly. There is therefore some prospect of being able in the not far distant future to prepare a climatology of that continent based on homogeneous data. As yet, however, owing to the short term of years covered by most of the records and the belated appearance of others, it is difficult to find any period that would yield adequate material for any inquiry that would apply to the same interval of time over the whole continent.

My excuse for presenting the following summary of the results of an inquiry into cloud amount for the above Republics is that the data, although not reduced to a homogeneous system, may be of some use in answering questions associated with civil aviation in South America. Outside of the Argentine Republic[1] little has been done in the way of working up cloud normals, although there is some information available for some stations in Chile[2] and in Peru.[3]

With these exceptions there was little information available beyond a few scattered references in the meteorological journals, special climatologies, and reports of expeditions, principally operating in the north-west corner of South America.[3]

The new data for Chile have been computed from the monthly values that appear in the annual reports issued by the Instituto Central Meteorologico y Geofisico during the period 1911–16,[4] the monthly means at 7 h., 14 h., and 21 h. along with the number of clear and cloudy days having been extracted for 32

[1] See *Climate of the Argentine Republic*, by W. G. Davis, 1902 ed. pp. 98-104, 1910 ed. pp. 31-32, 60-61, 80-81, 95-96.

[2] *Edinburgh, J. Scot. Meteor. Soc.* **15** (ser. 3) 1911, pp. 330, 331, 346. See also Publicatión No. 28, Inst. Meteor. y Geofis. de Chile, Santiago, 1919.

[3] Hann, J., "Zur Meteorologie von Peru," *Wien, Denkschr. Ak. Wiss.* **118**, Abt. IIa. Bowman, J., *The Andes of Southern Peru.* New York, 1916, pp. 121-181. *Peru-Bolivia Boundary Commission* 1911-13. *Reports of the British Officers of the Peruvian Commission.* Cambridge University Press, 1918.

[4] Nos. 3, 10, 15, 22, 25, and 26.

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stations on the coast (including 2 in the South Pacific) and 21 in inland or high-level situations. Of these 18 coastal and 6 inland stations afford complete data for the six years discussed, and in Table I. will be found monthly and annual values for 12 stations on the coast, where observations were made from January 1900 to July 1906, and again from 1911 to 1916. It may, however, be noted that in the former period the morning observation was made at 8 h. instead of 7 h. Only one longish record for an inland station, viz., Santiago, appears in this table based on the data from 1901 to 1909, and 1911 to 1916.

With the exception of some of the high-level stations in North Chile, which are of special interest, *monthly* values of cloud amount are not given for stations with less than 3 years' observations.

The Brazilian data have been compiled from various reports and for varying periods. For the State of São Paulo [1] the decade 1901–10 was selected in order that the results might be comparable with other data already published.[2] For 1901, however, the values for each of the hours 7, 14, 21 were not given, so that the year 1911 was taken to complete the decadal values for the individual hours (see Table VI.). There are returns for 5 coastal and 25 inland stations in this state, and the data in most cases cover 10 years. Long-period normals are available from one station on the coast and five inland (see Table I.).

Other data for Brazil have been compiled from the annual summaries given in the *Annuarios* of the Rio Observatory for the period 1911–17.[3] The values refer to 19 stations on the coast, and 14 in the interior, the data for Pará, Fortaleza, and Bello Horizonte having been derived from other sources. Six inland and five coastal stations afford data for the 7 years 1911–17. The mean cloud amount at each of the hours of observation is not given, but Dr. Morize, Director of the Rio Observatory, has kindly sent monthly values for 11 stations north of lat. 20° S. based on records for the years 1911–18, which supplement the more extensive material available for São Paulo. These data are summarised in Tables III., IV., and VI. Owing to frequent changes in the hours of observation long-period normals are only available for three Brazilian stations apart from those in São Paulo, and in the case of Rio are based on estimates of cloud amount made every third hour beginning at 1 h.

For the states of Minas Geraes [4] and Rio Grande do Sul [5] very complete climatological reports have appeared dealing with the years 1914–15 and 1915–16 respectively. As most of the returns refer to but two years, only the annual values have been considered, which are given along with a few other stations of short period in Table V.

The data utilised refer with only one or two exceptions to observations made at 7, 14, 21 h., and the first question that arises is, how far the mean of these hours represents the true daily mean, *i.e.* the mean which would have been available had observations been made at frequent intervals night and day? Only at Arequipa and Chosica in Peru were observations made at each hour of the 24, but at Rio de Janeiro and several stations on the littoral of Chile observations were made every third hour throughout the day.

Summarising the results (not printed) it may be said that observations of cloud amount made at the above three hours or a combination that differs very

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[1] Data from *Dados Climatologicas* of the Commissão Geographica e Geologica de São Paulo.

[2] *London Q. J. R. Meteor. Soc.* **45**, 1919, pp. 53-63.

[3] Ministerio do Agricultura Industria e Commercio, *Annuario* publicado pelo Observatorio Nacional do Rio de Janeiro, 1918, pp. 271-437; *ibid.* 1919, pp. 320-413.

[4] Estado do Minas Geraes, Servico de Meteorologia, Secretaria da Agricultura, *Dados Meteorologicos de 1910-1914.* Bello Horizonte 1916; *ibid. 1915.* Bello Horizonte, 1918.

[5] Estado do Rio Grande do Sul, *Dados Meteorologicos de 1915.* Porto Alegre, 1917; *ibid. 1916.* Porto Alegre, 1918.

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TABLE I.—MEAN PERCENTAGE CLOUD AMOUNT FOR LONG PERIODS. HOURS 7, 14, 21.

Note :—At the Stations in Chile the morning observation from January 1900 to July 1906 was made at 8 h. This does not apply to Santiago and Punta Arenas (Jesuit College). For heights and co-ordinates of Stations see Table II.

Stations.	Number of Years.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.	Range.
S. PAULO															
Coast.															
Iguape	18	63	62	60	54	59	55	54	60	69	70	64	62	61	16
Inland.															
Rio Claro	23	69	72	62	52	49	44	40	53	55	64	63	64	57	32
Campinas	23	65	66	56	42	42	42	33	37	54	58	56	62	51	33
Tatuhy	24	63	62	49	41	39	38	31	34	47	54	54	58	48	32
Ytu	22½	61	64	51	41	42	40	34	33	46	55	54	59	48	31
S. Paulo	26	72	71	67	65	64	60	54	55	66	66	65	65	64	18
Quixeramobim	20	60	65	65	57	55	49	38	33	31	35	44	53	49	34
Cuyaba	17	74	73	69	58	48	43	34	38	50	60	68	74	57	40
Rio de Janeiro*	27	66	59	61	58	56	54	50	58	73	72	71	68	62	23
CHILE															
Santiago	15	17	19	26	40	60	62	60	51	56	46	35	24	41	45
Iquique	12½	45	41	41	47	62	78	84	82	80	72	62	47	62	43
Caldera	,,	58	52	56	64	62	60	60	62	70	66	64	62	61	18
Punta Tortuga (Coquimbo)	,,	46	44	52	58	60	59	58	54	61	56	50	50	54	17
Punta Angeles (Valparaiso)	,,	31	33	41	48	55	58	58	48	46	47	34	38	45	27
Punta Carranza	12	28	32	40	48	62	62	57	50	45	43	38	35	45	34
Punta Tumbes	12½	27	32	41	50	64	64	61	56	52	45	38	31	47	37
Mocha West	,,	46	50	53	61	71	70	72	65	65	60	58	54	60	26
Punta Galera	,,	48	49	56	65	80	76	79	74	68	61	63	54	64	32
Punta Corona (Ancud)	,,	52	58	62	70	80	77	77	73	70	66	71	62	68	28
Evangelistas	,,	84	84	83	82	76	78	77	77	78	80	84	84	81	8
Dungeness	,,	66	59	59	59	57	58	58	54	54	56	65	68	59	14
Punta Arenas (Jesuit College)	,,	68	64	63	61	61	62	63	62	62	66	67	68	64	7
Punta Arenas (Jesuit College)	29	67	62	63	62	60	60	60	60	59	62	64	67	62	8
SOUTH PACIFIC															
Juan Fernandez	10¼	56	62	62	64	66	71	67	62	65	64	58	55	63	16

* Observations made eight times a day at intervals of 3 hours commencing at 1 h.

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little from them, give a very close approximation to the true daily mean. In a considerable number of cases the values are the same and rarely depart from the daily mean more than 2 or 3 per cent. A rather exceptional departure is shown at the Peruvian high-level station of Arequipa, where from January to March the mean of the cloud amount at 7, 14, and 21 h. is 7 per cent below the mean of the 24 hourly values, but at Chosica in the same Republic the seasonal departures do not exceed 2 per cent at any season. On the coast of Chile, ten stations extending from lat. 20° S. to 52° 30′ S. show a difference from 2 per cent above to as much below the average, the hours utilised being 6, 15, and 21. At Caldera (lat. 27° S.) the difference is − 3 per cent, which is the largest observed. At Rio de Janeiro the mean cloud amount at 7, 13, and 22 h. in spring and summer is the same as the daily mean, but in autumn and winter the above combination of hours is 3 per cent greater than the daily mean. Speaking generally, it may thus be said that the mean of the three hours selected agrees very closely with the daily mean derived from hourly or less frequent observations spread evenly over the 24 hours, at the few places where such data are available.

A further point on which information is desirable is how far do the short term means given in Table II. differ from the relatively long normals shown in Table I.? Here again the general agreement is very close except in two cases. With regard to the annual means, out of 23 stations 7 give exactly the same mean for the short as for the long periods. In a similar number of cases, viz. 7, the difference is ± 1 per cent, in three cases 2 per cent, and in 5 cases 3 per cent. In the case of Iquique and Evangelists Island the annual values from 1911 to 1916 are as much as 8 and 6 per cent respectively in excess of the long average which includes these years. Over the São Paulo plateau taking integrated values the mean monthly departures of the short from the long average show that cloud amount from January to May and in September was 2 per cent less during the decade discussed ; in June, October, and November the values are the same, and in July, August, and December the excess was 1 or 2 per cent. On the coast of Chile, including Santiago, the Junes and Septembers were relatively clear during the short period, the mean from Caldera to Punta Galera showing deficiencies of 5 per cent in both months, but during the rest of the year there was little difference between the means over the two periods. At Juan Fernandez the skies were rather cloudy, showing about 5 per cent excess from December to July, but from September to November conditions were about the same in both periods. At Quixeramobim there was a rather marked deficiency of cloud amounting to 5 per cent from September to March, while on the other hand the Aprils show an excess of 4 per cent.

Dealing with the integrated regional values given in Table III. we see that at inland stations summer is the cloudiest season of the year in Brazil, Peru, and North Chile and the clearest season in Chile between latitudes 27° and 41° S. Chilean coast stations down to lat. 44° S. have also their clearest skies at this season, but in the extreme south the reverse is the case, the maximum cloud amount being observed then. On the Brazilian coast summer is relatively clear except from 5° to 13° S., where as in inland situations in the same latitudes cloud amount is at a maximum. In autumn cloud conditions are in a state of transition, but in the High Andes of Chile, as well as on the Peruvian and southern Brazilian coasts, cloud amount falls to a minimum. Near the Equator the cloud amount is greatest. In winter the cloud amount is in general the reverse of that in summer. Thus regions which have their maximum in summer have their minimum in winter and vice versa except those situated on the coast of Brazil, where the minimum for the year takes place in spring as far south as 13° S. and the maximum for the year between

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TABLE II.—Mean Monthly, Annual, and Seasonal Percentage of Cloud Amount and Percentage Frequency of Clear and Cloudy Days from Observations made at 7, 14, and 21 h.

Stations.	South Latitude.	West Longitude.	Height.	Period.	Years.	Mean Amount.																Mean Annual.				Percentage Frequency (Annual).		Percentage Frequency of Clear and Cloudy Days by Seasons.							
																												Clear days.				Cloudy days.			
						Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.	Summer.	Autumn.	Winter.	Spring.	Range.	7 h.	14 h.	21 h.	Range.	Clear days <2.	Cloudy days >8.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.
Peru and Chile Coast, including island stations.			m.																															
Mollendo[1] (Peru)	17 5	73 0	24	1892–95	3½	48	43	*36*	*36*	55	78	86	**89**	88	85	72	63	65	51	42	84	82	42	81	43	79[1]	38	...	...	...	...	...	...	...	...
Arica . .	18 28	70 20	5	1911–16	6	45	44	*33*	42	53	64	**69**	**69**	67	60	58	46	54	45	43	67	62	24	78	25	59	53	14	18	21	24	2	7	13	12	26	19
Iquique . .	20 12	70 11	9	1911–16	6	54	49	*46*	52	73	90	**93**	91	91	79	72	54	70	52	57	91	81	39	78	68	63	15	12	51	22	21	1	4	23	33	82	64
Antofagasta .	23 39	70 25	5	1911–13	3	30	30	30	34	**40**	**40**	32	26	28	30	*24*	28	31	29	35	33	27	8	24	34	35	11	...	...	...	...	...	...	...	...	...	...
Taltal . .	25 25	70 34	39	1913–16	4	44	*32*	37	49	59	60	62	**68**	64	64	52	49	53	42	48	63	60	21	74	37	49	37	16	25	24	22	9	10	11	18	37	32
Caldera . .	27 3	70 53	28	1911–16	6	55	*47*	58	62	60	59	59	64	66	**67**	61	61	60	54	60	61	65	11	84	35	60	49	12	29	14	11	13	9	20	30	33	33
Pascua (Easter Is.)	27 10	109 26	30	1911–13	2½	55	*52*	58	59	63	69	64	64	66	61	64	57	61	55	60	66	64	11	65	66	51	15	4	24	6	5	1	2	14	20	34	29
Serena . .	29 54	71 15	35	1911–14	4	*34*	*34*	41	**58**	52	52	**58**	51	50	52	41	41	47	36	50	54	48	18	67	40	33	34	25	22	23	23	26	7	27	33	22	
Coquimbo . .	29 56	71 21	27	1911–16	6	*44*	46	51	56	57	57	**59**	51	58	57	47	48	53	46	55	56	54	10	74	46	37	37	20	28	16	20	23	22	13	32	35	31
Valparaiso .	33 1	71 38	41	1911–16	6	*31*	34	40	50	53	49	**58**	48	44	51	33	38	44	34	48	52	43	18	56	42	33	23	34	22	38	30	33	36	11	26	29	23
Juan Fernandez[2]	33 37	78 50	10	1911–16	6	63	67	67	70	69	**76**	72	64	66	64	*59*	60	66	63	69	71	63	8	71	66	63	8	6	35	7	3	4	9	31	37	41	30
Punta Carranza .	35 36	72 38	30	1911–16	6	*22*	30	39	47	**60**	53	55	51	38	43	35	32	**42**	28	49	53	39	25	48	44	34	14	39	23	58	34	25	37	13	30	32	16
Chanco . .	35 42	72 32	37	1911–14, 1916	5	*16*	21	29	39	**52**	49	49	47	39	**42**	31	31	37	23	40	48	37	25	44	37	31	13	47	20	63	45	37	44	9	24	30	18
Punta Tumbes .	36 57	73 6	91	1911–16	6	*23*	34	44	54	**64**	58	61	57	47	50	39	32	47	30	54	59	45	29	52	49	40	12	31	28	49	24	21	29	12	34	38	25
Concepción .	36 50	73 3	15	1911–15	5	*27*	28	41	55	**71**	66	68	58	48	50	44	34	49	30	56	64	47	34	55	52	41	14	30	28	52	24	16	27	11	34	43	22
Punta Lavapie .	37 8	73 25	46	1912–16	5	*20*	27	38	50	**63**	60	59	56	46	48	38	31	45	26	50	58	44	32	52	47	36	16	35	22	60	29	17	35	7	28	34	20
Contulmo . .	38 2	73 12	38	1911–16	6	*24*	30	39	52	**65**	59	62	61	54	54	47	37	48	30	52	61	52	31	51	50	44	7	30	28	48	28	18	27	10	32	40	30
Mocha West .	38 21	73 58	20	1911–16	6	*42*	49	52	61	**71**	66	**71**	63	60	58	56	53	58	48	61	67	58	19	66	57	53	13	15	33	24	15	9	12	22	40	41	29
Valdivia . .	38 48	73 14	15	1911–16	6	*41*	45	52	59	81	77	**82**	77	66	60	56	49	62	45	64	79	61	34	75	63	52	23	14	41	28	11	3	13	19	47	63	35
Puerto Dominguez	38 54	73 14	?	1913–16	4	*44*	48	62	66	80	74	**81**	76	67	60	66	48	64	47	69	77	64	30	69	60	62	9	12	42	20	8	8	13	17	42	64	43
Punta Galera .	40 1	73 44	40	1911–16	6	*48*	49	55	66	**81**	72	79	76	64	60	62	56	64	51	67	76	62	25	69	65	58	11	19	45	30	17	10	21	28	49	60	42
Osorno . .	40 35	73 9	24	1911–14	4	*40*	42	49	68	80	84	82	71	67	62	58	52	63	45	66	79	62	34	76	64	49	27	12	40	23	8	4	12	14	39	71	36
Puerto Montt .	41 28	72 57	5	1911–16	6	*57*	*57*	64	73	82	78	**84**	75	68	68	71	67	70	60	73	79	69	19	79	68	64	15	7	49	10	5	4	8	30	51	65	49
Punta Corona .	41 47	73 52	48	1911–16	6	*51*	58	60	75	**85**	80	84	76	70	66	76	68	71	59	73	80	71	21	73	68	70	5	13	56	23	10	8	13	39	60	70	55
Morro Lobos .	42 4	73 24	70	1912–16	5	*50*	54	56	65	76	76	**81**	71	69	61	66	60	65	55	66	76	65	**21**	69	67	59	10	12	42	19	12	7	10	28	41	59	41

[1] Hours, 7, 14, and 18.

[2] No data for 8 months in period.

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TABLE II. (*continued*).—MEAN MONTHLY, ANNUAL, AND SEASONAL PERCENTAGE OF CLOUD AMOUNT AND PERCENTAGE FREQUENCY OF CLEAR AND CLOUDY DAYS FROM OBSERVATIONS MADE AT 7, 14, AND 21 H.

(*Note*: At Santa Ana, Cuzco, and La Joya, the hours under Mean Annual are 8, 14, and 18, except at La Joya where the data refer to 7, 14, and 18 h.)

STATIONS.	South Latitude.	West Longitude.	Height.	Period.	Years.	Mean Amount.																Mean Annual.				Percentage Frequency (Annual).		Percentage Frequency of Clear and Cloudy days by Seasons.							
																												Clear days.				Cloudy days.			
						Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.	Summer.	Autumn.	Winter.	Spring.	Range.	7 h.	14 h.	21 h.	Range.	Clear days <2.	Cloudy days >8.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.
PERU AND CHILE COAST, including island stations—(*contd.*).	° ′	° ′	m.																															
Isla Guafo. .	43 34	74 45	140	1911–16	6	70	67	69	71	72	73	**76**	72	67	*65*	76	71	71	69	71	74	69	68	6	4	43	2	4	3	5	39	41	49	41
Melinka . .	43 44	73 46	5	1912–16	5	*46*	49	52	60	65	65	**73**	64	64	56	66	59	60	51	59	67	62	16	63	59	58	5	13	32	21	15	9	9	19	32	45	32
Evangelistas .	52 24	75 6	55	1911–16	6	88	89	**91**	89	85	84	84	*82*	84	86	89	88	87	88	88	83	86	5	88	87	86	2	3	81	0	5	4	3	87	85	73	79
Dungeness .	52 **24**	68 26	5	1911–16	6	66	58	61	61	59	56	60	*50*	53	54	63	**68**	59	64	60	55	57	9	61	62	54	8	9	25	3	9	14	11	29	25	25	22
Punta Arenas (Gobiernation Maritimo)	53 10	70 54	4	1911–16	6	72	71	72	68	69	68	70	*63*	67	67	73	**79**	70	74	70	67	69	7	72	74	65	9	4	43	0	5	9	**2**	52	**41**	40	40
Cabo San Isidro	53 47	70 58	20	1912–16	5	77	77	78	76	77	75	77	*71*	75	76	78	**81**	76	78	77	74	76	4	78	78	71	7	0	52	0	0	1	0	52	51	52	53
Bahia Douglas .	55 9	68 8	?	1914–16	3	75	70	64	69	64	63	67	*61*	*61*	66	75	**79**	68	75	66	64	67	11	74	71	59	15	4	35	0	4	7	3	51	27	28	34
PERU AND CHILE. INLAND.																																					
Above 200 metres.																																					
Peru.																																					
Chosica . .	11 51	76 35	2012	1889–90	1½	88	**97**	77	62	34	28	*18*	22	32	52	54	65	52[1]	83	58	23	46	62	50	46	63	17	...	...	..	...	...	...	...	...	...	...
Santa Ana[1] .	12 28	72 45	1040	1894–95	1½	**83**	67	70	48	53	47	*42*	65	72	67	60	67	62[1]	72	57	51	66	21	68	50	61	18	...	...	...	...	...	...	...	...	...	...
Cuzco[1] . .	13 27	72 0	3380	1894–95	1½	**70**	69	69	47	44	40	30	*25*	43	52	52	67	51[1]	69	53	32	49	37	72	48	73	25	...	...	...	...	...	...	...	...	...	...
Arequipa . .	16 22	71 33	2451	1890, 1900–03	4½	79	**81**	65	40	35	28	**27**	30	35	43	48	74	49[1]	78	47	28	42	50	28	20	51	31	...	...	...	...	...	...	...	...	...	...
La Joya[1] . .	16 46	71 15	1260	1892–95	3½	53	**55**	45	32	31	24	24	*18*	24	30	33	44	34[1]	51	36	22	29	29	28	5	33	28	...	...	...	...	...	...	...	...	...	...
Chile.																																					
Collahuasi (La Grande)	20 59	68 45	4805	1915	1	37	**57**	27	14	*9*	24	25	18	10	22	14	24	23	39	17	22	15	24	25	31	16	15	57	5	29	73	64	62	6	0	9	3

[1] At 8, 14, and 20 h. except Santa Ana where the hours were 8, 14, and 18.

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TABLE II. (*continued*).—MEAN MONTHLY, ANNUAL, AND SEASONAL PERCENTAGE OF CLOUD AMOUNT AND PERCENTAGE FREQUENCY OF CLEAR AND CLOUDY DAYS FROM OBSERVATIONS MADE AT 7, 14, AND 21 H.

STATIONS.	South Latitude.	West Longitude.	Height.	Period.	Years.	Mean Amount.												Summer.	Autumn.	Winter.	Spring.	Range.	Mean Annual.				Percentage Frequency (Annual).		Percentage Frequency of Clear and Cloudy Days by Seasons.							
						Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.						7 h.	14 h.	21 h.	Range.	Clear days <2.	Cloudy days >8.	Clear days.				Cloudy days.			
																													Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.
PERU AND CHILE. INLAND.																																			
Above 200 *metres* (*continued*).																																			
Chile.			m.																																
Oyahue[1]	21° 13′	68° 16′	3695	1913, 15, 1916	3	38	**44**	25	18	*9*	22	23	20	21	24	23	28	25	37	17	22	23	20	19	33	22	14	53	3	30	68	58	55	5	3	2	2
Chuquicamata	22 18	68 55	2710	1915	1	(13)	**21**	11	6	*4*	12	17	16	7	15	9	**21**	13	18	7	15	10	11	17	13	8	9	(77)	(1)	64	85	74	84	1	0	3	0
Calama	22 27	68 56	2260	1913–14	2	**14**	**14**	6	10	11	5	5	8	*4*	5	11	*4*	8	11	9	6	7	5	10	11	3	8	91	0	87	89	96	92	0	0	0	0
Refresco	25 19	69 52	1850	1914–16	3	9	4	6	9	13	17	**24**	9	13	9	*5*	4	10	6	9	17	8	11	10	12	8	4	83	3	93	83	72	85	1	2	8	0
Copiapo	27 21	70 21	370	1911–16	6	*24*	*24*	26	28	32	31	30	28	**34**	31	27	28	29	25	29	30	31	6	62	14	11	51	35	4	34	34	43	29	0	3	8	3
San Felipe	32 45	70 44	636	1913–16	4	8	7	20	30	38	38	**49**	33	25	28	14	10	25	8	29	40	22	32	28	27	19	9	65	14	86	58	54	64	1	16	28	10
Los Andes	32 50	70 37	816	1911–16	6	*12*	14	22	44	50	52	**55**	50	49	47	34	21	37	16	39	52	43	36	42	41	28	14	45	21	74	43	27	36	4	22	37	20
Lo Espejo	33 24	70 42	580	1912–14	3	*14*	17	27	41	62	63	**65**	58	55	50	38	25	43	19	43	62	48	43	46	43	36	10	40	25	69	36	23	32	3	24	46	25
Santiago	33 27	70 42	520	1911–16	6	*17*	*17*	27	44	56	57	**61**	55	50	51	37	26	41	20	42	58	46	38	48	42	34	14	39	21	68	38	23	30	4	22	35	22
El Teniente	34 6	70 38	2134	1912–16	5	17	*14*	26	40	49	49	**51**	48	43	38	38	20	36	17	38	49	40	32	34	46	28	18	49	21	71	46	35	43	6	22	32	26
Rancagua	34 10	70 45	500	1911–14	4	*17*	18	27	46	64	58	**66**	64	60	58	46	32	46	22	46	63	55	41	52	46	38	14	34	27	62	34	18	22	6	26	46	31
San Fernando	34 35	71 0	350	1911–16	6	*14*	15	28	48	64	64	**66**	61	52	53	37	27	44	19	47	64	47	45	55	43	35	20	34	25	68	29	14	25	6	27	43	23
Longuimay	38 26	71 14	970	1914–16	3	*28*	*28*	49	61	66	71	**74**	72	61	53	58	37	55	31	59	72	57	41	62	54	48	14	20	33	48	13	5	15	9	34	54	35
Below 200 *metres.*																																			
Quillota	32 53	71 16	128	1913–16	4	19	*16*	33	43	45	47	**57**	45	44	53	32	32	39	22	40	50	43	28	50	34	33	17	39	21	52	42	29	32	7	17	30	30
Talca	35 26	71 40	107	1911–16	6	*14*	16	25	48	67	63	**64**	56	50	50	37	25	43	18	47	61	46	43	50	45	32	18	37	24	68	34	16	32	4	27	41	21
Linares	35 50	71 36	157	1911–14	4	*16*	18	25	48	**71**	65	70	56	53	53	43	34	46	23	48	64	50	41	55	46	32	23	31	23	60	29	13	22	4	23	41	24
Angol	37 48	72 41	72	1912–14	3	*13*	20	26	47	61	**62**	59	53	50	42	34	30	41	21	45	58	42	37	44	46	34	12	39	24	64	37	22	32	5	26	40	22
Traiguen	38 15	72 40	177	1911–16	6	20	*19*	36	58	71	**72**	**72**	64	54	53	40	28	49	22	55	69	49	47	61	45	41	20	31	33	61	23	10	30	10	36	52	32
Temuco	38 45	72 35	112	1911–16	6	*26*	31	48	62	65	68	**70**	65	54	56	50	40	53	32	58	68	53	36	66	52	41	25	24	30	42	18	12	22	11	34	46	30
Puntiagudo	41 5	73 17	190	1914–16	3	52	*46*	58	67	**85**	71	81	71	71	59	66	56	65	51	70	74	65	23	70	67	60	10	13	46	23	11	8	12	28	51	61	44

[1] Called Ollagüe in Reports for 1913 and 1915.

TABLE II. (*continued*).—MEAN MONTHLY, ANNUAL, AND SEASONAL PERCENTAGE OF CLOUD AMOUNT AND PERCENTAGE FREQUENCY OF CLEAR AND CLOUDY DAYS FROM OBSERVATIONS MADE AT 7, 14, AND 21 H.

STATIONS.	State.	South Latitude.	West Longitude.	Height.	Period.	Years.	Mean Amount.													Summer.	Autumn.	Winter.	Spring.	Range.	Percentage Frequency (Annual).		Percentage Frequency of Clear and Cloudy Days by Seasons.							
																											Clear days <2.				Cloudy days >8.			
							Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.						Clear days <2.	Cloudy days >8.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.
BRAZIL. COAST.		° ′	° ′	m.																													
Pará	Pará	1 27	48 29	10	1904–10	7	64	**77**	75	73	63	54	43	41	40	*35*	41	53	55	65	70	46	39	31	...	...	...	...	...	...	...	...	...	...
Turyassu	Maranhão	1 25	45 15	15	1912–16	6	73	79	**83**	**83**	70	60	52	*46*	47	51	48	59	63	70	79	53	49	30	1	30	0	0	1	1	44	57	13	8
Manáos	Amazonas	3 8	59 45	45	1911–17	7	63	**66**	**66**	**66**	65	63	60	*59*	60	63	63	65	63	65	66	61	62	5	0	11	0	0	0	0	16	16	4	9
Fortaleza	Ceará	3 42	38 30	2	1904–07	4	61	**77**	70	61	59	52	37	*36*	45	48	56	59	55	66	63	42	50	24	...	...	...	...	...	...	...	...	...	...
Fernando Noronha	Pernambuco	3 50	30 20	93	1911–17	7	53	54	56	**63**	58	49	44	45	36	*35*	41	52	49	53	59	46	37	22	14	15	10	9	17	21	18	24	12	3
Barro do Corda	Maranhão	5 31	45 16	80	1913–16	4	**72**	68	68	69	50	45	*34*	46	50	60	63	**72**	58	71	62	42	58	29	11	23	2	7	29	6	42	25	8	18
Imperatriz [1]	,,	5 32	47 35	59	1914–17	4	69	**70**	59	60	38	30	26	*18*	30	34	44	63	45	67	52	25	36	42	34	21	11	22	63	38	43	24	7	9
Natal	Rio Grande do Norte	5 47	35 12	3	1913–17	5	56	55	51	60	58	**63**	52	48	46	*41*	46	52	52	54	56	54	44	12	6	13	4	3	10	7	16	18	16	2
Guarabira	Parahyba do Norte	6 49	35 27	100	1912–17	6	54	58	59	58	59	**63**	61	*49*	52	*49*	51	52	55	55	59	58	51	8	3 [3]	9	...	...	...	... [3]	6	11	16	1
Goyanna [1]	Pernambuco	7 34	35 0	14	1912–15	4	60	60	57	60	67	69	**72**	66	51	47	*46*	52	59	57	61	69	48	21	8	26	9	7	7	11	24	27	40	11
Recife	,,	8 4	34 52	30	1911–17	7	46	50	47	48	57	**59**	57	55	39	*33*	38	42	48	46	51	57	37	20	9	12	7	8	7	15	9	15	22	3
Aracagú	Sergipe	10 55	37 4	4	1911–16	6	45	51	48	49	57	**59**	58	52	45	43	*40*	*40*	49	45	51	56	43	13	11	14	13	9	4	16	13	15	20	9
Ondina	Bahia	13 12	38 30	47	1911–17	7	58	57	57	62	66	**67**	65	59	*54*	58	*54*	58	60	58	62	64	55	9	2	21	2	0	1	3	20	21	22	20
Campos	Rio de Janeiro	21 40	41 30	10	1912–17	6	68	52	57	61	48	47	*41*	52	50	69	**72**	70	57	63	55	47	64	17	21	34	17	21	32	16	43	28	23	42
Batalha	,,	22 43	43 9	5	1911–16	6	67	53	61	57	53	59	*50*	57	**73**	72	70	70	62	63	57	55	72	17	13	38	14	14	16	8	41	29	32	50
Rio de Janeiro [2]	,,	22 54	43 10	62	1911–17	7	65	54	61	56	54	54	54	*53*	70	**73**	70	70	61	63	57	54	71	17	14	37	14	13	21	9	40	30	29	50
Ubatuba	São Paulo	23 30	45 25	10	1901–10	10	74	70	68	61	60	*53*	54	61	79	**84**	78	73	68	72	63	56	80	24	12	48	8	13	23	5	49	41	36	65
São Sebastio	,,	23 48	45 20	10	1906–12	6	59	60	58	*49*	50	50	52	53	69	**71**	63	58	58	59	52	52	68	16	19	33	10	22	32	12	31	25	34	43
Santos	,,	23 56	46 19	10	1901–10	10	64	67	63	56	53	54	*51*	63	72	**74**	70	69	63	67	57	56	72	16	16	42	13	20	21	9	44	34	38	52
Iquape	,,	24 45	47 48	10	1901–10	10	61	64	64	*55*	57	*55*	*55*	66	**71**	70	64	66	62	64	59	59	68	9	10	40	9	11	12	7	40	36	37	49
Cananea	,,	25 1	47 57	10	1901–10	10	65	67	62	58	55	*47*	50	58	65	**68**	63	63	60	65	58	52	65	13	15	37	10	16	24	11	41	32	32	43
Paranagua [1]	Paraná	25 34	48 30	3	1911–16	6	70	72	72	65	*61*	75	68	74	76	**83**	72	74	72	72	66	72	77	11	6	51	3	8	7	4	50	42	47	64

[1] At 7 and 21 hrs. only. [2] Every 3 hrs. beginning at 1 hr. [3] In the remarkably hot year of 1915 there were 65 clear days at this station and only 2 in the other 6 years, so that seasonal values of clear days are not given.

TABLE II. (*continued*).—MEAN MONTHLY, ANNUAL, AND SEASONAL PERCENTAGE OF CLOUD AMOUNT AND PERCENTAGE FREQUENCY OF CLEAR AND CLOUDY DAYS FROM OBSERVATIONS MADE AT 7, 14, AND 21 H.

STATIONS.	State.	South Latitude.	West Longitude	Height.	Period.	Years.	Mean Amount.													Summer.	Autumn.	Winter.	Spring.	Range.	Percentage Frequency (Annual).		Percentage Frequency of Clear and Cloudy Days by Seasons.							
							Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.								Clear days <2.							
																									Clear days <2.	Cloudy days >8.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Cloudy days >8.			
																											Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.
BRAZIL. COAST (*continued*).		° ′	° ′	m.																													
Blumenau	Santa Catherina	26 55	49 3	24	1911–16	6	55	79	76	72	71	**82**	69	70	**82**	78	77	73	73	69	73	74	79	10	7	57	3	7	10	7	57	48	58	65
Brusque	,,	27 5	48 59	24	1911–16	6	68	65	65	58	55	67	53	60	72	**73**	71	71	65	68	59	60	72	13	10	43	6	12	14	7	43	34	40	53
Florianopolis	,,	27 35	48 33	3	1911–16	6	66	66	62	58	51	64	52	58	**72**	68	68	67	63	66	57	58	69	12	11	36	3	13	20	7	37	26	34	47
Porto Alegre	Rio Grande do Sul	30 4	51 8	26	1911–17	7	51	50	53	49	56	53	**59**	55	63	56	55	49	54	50	53	56	58	8	20	30	23	20	17	19	24	26	33	35
Monte Video	Uruguay	34 52	56 13	29	1901–10	10	43	44	45	48	54	**64**	59	55	55	51	47	42	51	43	49	59	51	16	...	...	...	...	...	...	...	...	...	...	...
BRAZIL. INLAND.																																	
Quixeramobim	Ceará	5 16	39 15	207	1911–17	7	56	59	**62**	61	55	49	37	32	26	31	37	47	46	54	59	39	31	28	18	10	9	7	24	30	17	20	4	0
Caetité	Bahia	14 2	42 37	900	1911–17	7	58	55	48	56	49	46	36	33	35	49	53	**59**	48	57	51	38	46	19	19	21	12	15	23	28	33	18	11	22
Cuyuba	Matto Grosso	15 35	56 0	235	1911–17	7	76	**77**	72	60	48	45	36	36	53	58	71	74	59	76	60	39	61	37	16	33	0	15	35	14	53	30	14	35
Formosa	Goyaz	16 8	45 2	911	1914–17	4	76	68	62	59	47	39	31	31	26	57	70	**78**	54	74	56	34	51	40	18	30	1	8	37	24	58	30	4	26
Montes Claros	Minas Geraes	16 43	43 52	618	1911–16	6	**60**	44	48	39	34	31	24	26	27	51	52	59	41	54	40	27	43	27	34	18	19	30	52	35	30	14	4	22
Catalão	Goyaz	18 8	47 30	875	1913–17	5	78	**71**	65	49	37	34	22	21	33	54	69	**81**	51	77	50	26	52	51	25	29	2	20	52	25	59	25	3	29
Bello Horizonte	Minas Geraes	19 55	43 5	857	1910–15	6	68	51	56	49	43	50	38	41	50	53	66	**70**	53	63	49	43	56	20	11	22	6	7	17	10	35	17	11	19
Santa Rita	S. Paulo	20 3	47 47	600	1901–10	10	61	61	49	35	30	26	23	23	31	47	55	**63**	42	62	38	24	44	38	30	16	11	32	52	25	34	10	3	17
Franca	,,	20 32	47 25	996	1901–12	9½	**66**	64	62	47	43	42	32	35	47	62	63	65	52	65	51	36	57	29	16	24	3	14	33	14	36	18	10	31
Riberão Preto	,,	21 10	47 59	560	1901–10	10	64	67	57	43	37	39	31	36	47	58	58	**68**	50	66	46	35	54	31	21	24	7	22	36	16	38	17	12	29
Barbacena	Minas Geraes	21 13	43 47	1150	1911–17	7	73	66	55	58	47	49	43	49	59	69	71	**78**	60	72	53	47	66	25	18	36	6	23	28	13	54	26	20	44
Jaboticabal	S. Paulo	21 14	48 19	577	1901–10	5½	60	66	53	39	34	39	31	28	33	54	58	**67**	47	64	42	33	48	31	21	23	6	22	36	19	36	13	21	21
Mattão	,,	21 36	48 23	560	1901–10	10	64	68	55	45	42	39	39	41	61	64	58	**70**	54	67	47	40	61	27	18	27	6	19	32	12	44	17	12	34
Ibitinga	,,	21 45	48 51	465	1902–11	10	60	62	50	36	40	40	33	32	48	53	52	**63**	47	62	42	35	51	27	28	21	11	31	43	27	34	13	11	25
Juiz de Fora	Minas Geraes	21 46	43 21	682	1911–17	7	71	60	65	63	55	59	51	55	57	73	71	**74**	63	68	61	55	67	13	7	35	3	5	11	9	44	28	22	46
Pocas de Caldos	S. Paulo	21 47	46 34	1186	1903–12	7	71	71	60	42	41	45	34	35	46	61	60	**74**	53	72	48	38	56	34	23	29	6	26	39	22	49	21	14	32
San Carlos	,,	22 1	48 12	842	1901–10	10	67	**74**	64	45	41	40	33	35	39	56	58	70	52	70	50	36	51	34	22	29	7	20	38	24	48	23	14	32
Brotas	,,	22 17	48 8	630	1901–10	10	63	**66**	55	42	39	40	34	36	49	55	52	**66**	50	65	45	37	52	28	24	25	12	26	36	23	41	18	14	28
Araras	,,	22 22	47 21	614	1902–12	9⅔	59	**65**	49	41	43	42	35	37	41	55	58	64	49	63	44	38	51	25	22	21	9	25	35	21	33	15	11	23

TABLE II. (*continued*).—MEAN MONTHLY, ANNUAL, AND SEASONAL PERCENTAGE OF CLOUD AMOUNT AND PERCENTAGE FREQUENCY OF CLEAR AND CLOUDY DAYS FROM OBSERVATIONS MADE AT 7, 14, AND 21 H.

STATIONS.	State.	South Latitude.	West Longitude.	Height.	Period.	Years.	Mean Amount.													Summer.	Autumn.	Winter.	Spring.	Range.	Percentage Frequency (Annual).		Percentage Frequency of Clear and Cloudy Days by Seasons.							
																											Clear days <2.				Cloudy days >8.			
							Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.						Clear days <2.	Cloudy days >8.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May.	June-Aug.	Sept.-Nov.
BRAZIL. INLAND (*continued*).		° ′	° ′	m.																													
Vaosouras	Rio de Janeiro	22 24	43 39	436	1912–17	6	69	60	64	64	55	55	*51*	54	70	73	**75**	73	64	67	61	53	73	20	12	40	9	11	20	8	47	35	27	52
Rezende	,,	22 28	44 27	399	1913–17	5	77	70	**78**	72	59	59	*54*	59	67	77	76	77	69	75	70	57	73	18	8	46	10	4	10	7	56	48	27	53
Petropolis	,,	22 31	43 10	816	1913–17	5	66	52	57	56	44	49	*39*	49	52	61	**73**	66	55	61	52	46	62	16	22	33	13	22	34	18	36	28	25	43
Alto do Itatiayo	,,	22 57	44 50	2210	1914–17	4	**78**	71	60	63	46	49	*37*	43	62	69	76	**78**	61	76	56	43	69	33	14	40	1	14	32	10	57	40	18	46
São Paulo dos Agudos	S. Paulo	22 25	48 58	602	1905–12	8	52	**63**	40	35	32	31	31	*29*	34	45	42	58	41	58	36	30	40	28	35	18	18	42	44	35	27	15	11	19
Rio Claro	,,	22 25	47 34	614	1901–11	10	71	**73**	58	50	50	50	*43*	52	61	68	66	72	60	72	53	48	65	24	17	36	7	17	28	15	57	27	21	40
Campos Novos	,,	22 34	50 12	487	1901–10	10	62	**66**	48	44	51	48	44	*39*	44	54	54	63	51	64	48	44	51	20	20	26	10	20	27	25	40	18	17	29
Braganca	,,	22 38	46 35	840	1901–10	10	70	**72**	62	48	45	46	*38*	40	42	58	60	71	54	71	52	41	53	30	19	30	6	20	32	19	48	28	16	29
Bananal	,,	22 40	44 17	450	1902–12	4½	57	61	60	56	54	*44*	52	46	60	**66**	60	58	56	59	57	47	62	15	15	25	14	11	27	9	24	23	18	34
Bocaina	,,	22 43	44 32	1740	1914–17	4	67	61	67	56	44	45	*38*	40	49	62	**69**	**69**	56	66	56	41	60	25	20	32	7	21	35	16	41	33	17	35
Amparo	,,	22 44	46 50	658	1905–12	7⅛	58	**64**	50	36	36	39	39	*33*	41	54	52	62	47	61	41	37	49	24	27	20	10	35	41	23	34	14	10	22
Piracicaba	,,	22 44	47 38	550	1903–12	10	67	**71**	62	62	52	61	54	*52*	66	67	62	68	62	**69**	59	56	65	13	9	31	3	10	15	5	44	23	24	32
Villa Jaguaribe	,,	22 44	45 36	1580	1905–12	7	**80**	48	43	27	26	30	29	*22*	36	46	46	45	37	48	32	27	43	21	42	17	21	49	62	36	26	11	11	20
Campinas	,,	22 54	47 16	665	1901–10	10	62	**66**	52	42	42	42	*36*	39	55	57	55	65	51	64	45	39	56	25	21	24	9	24	38	14	37	16	15	30
Botucatú	,,	22 54	48 46	800	1902–11	10	51	**54**	40	35	31	40	31	*30*	40	47	43	52	41	52	35	34	43	18	38	19	22	43	51	35	22	13	15	24
Taubate	,,	23 2	45 33	583	1901–10	10	**75**	72	68	54	53	53	*45*	50	61	69	69	73	62	73	58	49	66	24	14	39	5	14	25	11	52	32	25	47
Tatuhy	,,	23 21	47 50	595	1901–10	10	62	**63**	49	39	38	37	*33*	35	45	54	55	**63**	48	63	42	35	51	28	26	24	11	32	38	23	35	18	15	29
Ytú	,,	23 16	47 37	583	1901–10	10	56	**62**	48	37	38	38	*35*	*35*	47	53	50	56	46	58	41	36	50	22	26	20	12	29	38	27	30	14	13	23
Jacarehy	,,	23 18	45 58	565	1901–10	10	74	**77**	72	64	61	59	*52*	58	68	72	72	**77**	67	76	66	56	71	20	3	40	3	2	4	4	55	35	24	47
Estacion Missionera	Paraguay	23 23	58 25	110	1896–1901	4½	47	49	44	50	43	**56**	*40*	50	43	51	51	53	48	50	46	49	48	4	...	...	...	...	...	...	...	...	...	...
S. Paulo	S. Paulo	23 34	46 55	761	1901–10	10	66	**70**	65	62	61	56	*52*	55	64	65	66	66	62	67	63	54	65	13	9	33	8	6	15	9	40	**29**	26	38
Apiahy	,,	24 30	48 52	885	1903–12	10	70	76	65	57	61	57	*56*	*56*	70	**77**	72	72	66	73	61	56	73	17	12	45	4	13	23	8	53	37	36	55
Curitiba	Parana	25 25	49 18	908	1911–16	6	63	69	68	60	61	68	51	58	68	71	69	70	65	67	63	59	69	10	8	40	3	8	13	8	41	34	38	47

21° and 30° S. Inland the mean annual cloud amount varies from about 10 per cent in the High Andes between 22° and 25° S. to 65 per cent in lat. 41° S. The values are also high (60 per cent) in the south of Brazil. At coastal stations the cloud amount is on the whole relatively high except on the Chilean littoral between 33° and 38° S. where it is 45 per cent. More than half of the regional groups have from 60 to 70 per cent, rising to over 80 per cent at Evangelists Island, but showing a rapid clearing of the sky to the eastward, along Magellan Straits. Taking the integrated means, it will be seen that the cloudiest time is very generally at 7 h. The exceptions are at high-level or inland stations in Peru and Chile between 12° and 21° S. At Brazilian coastal stations near the Equator, and also from 21° to 25° S., the amount of cloud at 7 h. is below the mean of the day. At 14 h. cloud conditions are, broadly speaking, in a transitional state, but in Peru, both at high and low levels, and at Chilean coastal stations as far south as lat. 27° S., the minimum cloud amount is recorded then. On the other hand, the maximum cloud is recorded at this hour in the High Andes of Chile, on the Brazilian inland plateau from 16° to 23° S., and on the Brazilian coast near the Equator. At 21 h. clear skies predominate, the minimum for the day being very generally reached, but at high-level Peruvian stations and on the coast of São Paulo cloud amount is at a maximum. In the latter region, however, the daily range is hardly appreciable. The difference between the clearest and cloudiest hours as shown by the tri-daily observations exceed 3 units on the coast of Peru and Chile from 17° to 33° S. rising to over 4 units between 25° and 27° S. On the other hand, it is less than one unit (*i.e.* 10 per cent) in the clear Andean zone in Chile between 22° and 25° S., in the South Pacific from 27° to 33° 30′ S., and at sea-level stations in the extreme south of Chile as well as at Brazilian stations near the Equator.

The diurnal range of the cloud amount is in many cases determined by purely local factors. On the coasts of Chile and Peru north of about lat. 33° S. the effect of land and sea breezes is most marked. A feature of this region is the cloudiness of the morning and forenoon hours, owing to the contact of the land breeze with the cold waters of the Humboldt current. Thus at Punta Caldera in lat. 27° S. the average wind at 6 a.m. on the mean of the year is about NE and the mean cloud amount 82, at 9 a.m. the wind is WNW and the cloud has fallen to 75, while by 3 p.m. the wind has changed to SW, *i.e.* off the sea, and the cloud amount has fallen to 35.[1] At Lagunas, a little to the south-east of Iquique a sudden change in wind direction takes place between 1 and 3 p.m., owing to the indraught from the sea to the sun-baked land, and at Santa Fé seventy miles inland this sea wind, owing to its having crossed a desert region, becomes very hot and unpleasant. At Copiapo (height 370 m.), the capital of the province of Atacama in about the same latitude as Punta Caldera and 30 miles inland, the changes are even more remarkable, the mean annual cloud amount being 62 at 7 h., 14 at 14 h., and 11 at 21 h., and in the summer, when land and sea breezes are most marked, the values are 67, 5, and 4 respectively. The effect of land and sea breezes is also prominently shown in the diurnal range of cloud on many parts of the Brazilian coast.

Over Chile and Brazil the diurnal range of cloud in general conforms to certain well-defined types. Antofagasta, however (lat. 23° 39′ S.), is an exception, as in this case cloud amount shows a steady *increase* throughout the day. Thus observations taken from July 1903 to 1906 and from 1911 to 1913 give a mean cloud of 25 at 7.30 h., 37 at 14 h., and 42 at 21 h. Four and a half years' data ending December 1910 give 33 at 7.30 h., 38 at 10 h., and 41 at 16 h. This type of cloud distribution is also specially marked at Pará from

[1] See "Climate of Chile," *Edinburgh, J. Scot. Meteor. Soc.* **15** (ser. 3), 1911, pp. 325–331.

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TABLE III.—Showing the Seasonal and Annual Percentage Amount of Cloud in Various Zones and the Mean Annual Cloud Amount at 7, 14, and 21 h. Also the Mean Annual Percentage Frequency of Clear and Cloudy Days.

Stations.	No. of Stations.	Lat. S.	Mean Height.	Mean Percentage Cloud Amount by Seasons. XII.-I.-II.	III.-V.	VI.-VIII.	IX.-XI.	Annual.	Mean Annual. * 7 h.	14 h.	21 h.	Range.	Percentage Frequency. Clear days <2.	Cloudy days >8.
Inland or High Level Stations.			Metres.											
Peru	5	12-17	2072	71	50	31	47	50	49	34	56	22[1]	...	...
Chile	2	21	4250	38	17	22	19	24	22	32	19	13	55	4
,,	3	22-25	2273	12	8	13	8	10	12	12	6	6	84	1
,,	8	27-35	738	18	39	52	42	38	46	38	29	17	43	20
,,	6	33-39 †	126	23	49	62	47	45	54	45	36	18	34	26
,,	1	38½	970	31	59	72	57	55	62	54	48	14	20	33
,,	1	41	190	51	70	74	65	65	70	67	60	10	13	46
Brazil	3	5-15½	447	62	54	39	46	50	66	51	39	27[1]	18	21
,,	4	16-20	815	66	49	32	51	50	54	63	45	18[1]	22	25
,,	9	20-22	753	66	49	38	56	52	51	58	41	17[2]	20	26
,,	18	22-23	786	64	50	42	57	53	51	54	44	10[2]	22	28
,,	7	23-25½	697	69	56	49	64	60	67	59	52	15[2]	14	34
Coast Stations.														
Peru	1	17	24	51	42	84	82	65	81	43	79	38[1]	...	...
Chile	2	18½-20	7	48	50	79	72	62	78	46	61	32	13	34
,,	2	25-27	33	48	54	62	62	56	79	36	54	43	14	27
,,	3	30-33	34	39	51	54	48	48	66	43	34	32	26	24
,,	6	35-38	43	28	50	57	44	45	50	47	38	12	35	25
,,	10	38½-44	41	53	67	75	64	65	71	64	59	12	12	42
,,	1	52½	55	88	88	83	86	86	88	87	86	2	3	81
,,	4	52½-55	10	73	68	65	67	68	71	71	62	9	4	39
S. Pacific	2	27-33½	20	60	64	68	63	64	68	66	57	11	7	42
Brazil	5	1-4	31	64	68	50	47	57	52	62	50	12[1]	5	19
,,	8	5-13	42	57	56	52	46	53	62	55	46	16[1]	11	17
,,	8	21-25	16	64	57	54	70	61	60	62	63	3[2]	15	39
,,	5	25-30	16	65	61	64	71	65	...	...	...	...	11	43

* The mean annual amount of cloud at 7, 14, and 21 h. in the zones indicated by (1) is based in general on a smaller number of records than those utilised for the other data given. In the zones marked (2) only the São Paulo data given in Table VI. are available. North of latitude 20° S. the Brazilian stations utilised were as follows: *Inland*: Quixeramobim, Caetité, Cuyuba, Formosa, Catalão, Bello Horizonte. *Coast*: Pará, Turyassu, Manáos, F. Noronha, Natal, Aracagú, Ondina.

† Six stations below 200 metres.

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April to August, but Antofagasta is the only place where it persists in a marked degree throughout the months of the year. At inland stations the percentage frequency of clear days exceeds 50 per cent in the High Andes of Chile, rising to 84 per cent between 22° and 25° S., but at Longuimay in 38° 30′ S. the most southern high-level station in Chile where observations are made, as well as in the north and south of Brazil, clear days are infrequent, falling to less than 20 per cent in several of the divisions.

At stations near the sea clear days rise to their maximum frequency, 35 per cent, on the coast of Chile between latitudes 30° and 38° S., but a glance at the values shows their infrequency in other coastal regions, except the region to the north of this specially favoured zone. Except in middle latitudes clear days on the Chilean coast are less than 15 per cent, falling to 5 per cent or less in the region of the Magellan Straits. In the South Pacific represented by Juan Fernandez and Easter Island, the mean is only 7 per cent. Brazilian coastal stations have few clear days, their absence being specially marked near the Equator, but further south a distinct improvement is apparent. Giving equal weight to the regional means the average annual percentage frequency of clear days is 41 at inland or high-level stations in Chile, and 15 per cent on the coast, whereas in Brazil the values are 19 per cent and 10 per cent respectively. The extremes at Chilean coast stations (Table II.) are 47 at Chanco in latitude 36° S., while at Cape San Isidro, no great distance from the Pacific entrance to Magellan Straits, none are recorded. At high levels in Chile the skies are very clear, 91 per cent at Calama and 83 per cent at Refresco, falling to 20 per cent at Longuimay in 38° 30′ S. and to 13 at Puntiagudo in 41° S. At strictly coastal Brazilian stations Campos in 22° S. has 21 per cent, while at Turyassu near the Equator there is only 1 per cent, and at Manáos none are recorded. In the interior Villa Jaguaribe in São Paulo has 42 per cent, and Jacarehy in the same state 3 per cent, these places having a large and small rainfall respectively. Cloudy days are practically absent in the High Andes of Chile, three stations from 22° to 25° S. having only 1 per cent, but their frequency in general increases down to lat. 41° S. In Brazil the regional values are comparatively uniform, varying from 22 to 36 per cent. On the coast of Chile the extreme north has 34 per cent of cloudy days diminishing to 24 per cent between 30° and 33° S., and increasing again rapidly to 81 per cent at Evangelists Island, a distinct improvement being shown in Magellan Straits and Tierra del Fuego, where the values fall to 39 per cent. In Brazil at low levels the mean frequency is 18 per cent between the Equator and 13° S., rising to over 40 per cent between 21° and 30° S. At places as far apart as Iquique, Ancud, and at Cape San Isidro in Chile more than half the days are cloudy, but at Arica in the extreme north of Chile cloudy days fall to 18 per cent and at Dungeness at the Atlantic entrance to the Straits of Magellan the value is only 25 per cent. At high-level stations Calama has no cloudy days, the values from 21° to 27° S. rising no higher than 5 at any station, but from 33° to 46° S. all the stations have over 20 per cent, rising to over 30 per cent south of latitude 38° and to 46 per cent in 41° S., south of which there are no high-level stations. At Brazilian low-level or coastal stations, about half the days are cloudy at Ubatuba, Paranagua, and Blumenau, but at Guarabira in 7° S. the value is under 10 per cent. In inland situations a few stations in the states of Rio de Janeiro, São Paulo, and Parana exceed 40 per cent, but at Quixeramobim (Ceará) the values fall to 10 per cent, and there are a few others with less than 20 per cent in the states of Minas Geraes and São Paulo. The average percentage frequency of cloudy days is 22 at inland or high-level stations in Chile and 39 per cent on the coast, the corresponding figures for Brazil being 27 and 29 per cent.

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TABLE IV.—Showing the Seasonal Amount of Cloud in various Zones at 7, 14, and 21 h. and the Seasonal Percentage Frequency of Clear and Cloudy Days.

Stations.	No. of Stations.	Lat. S.	Mean Height.	Mean Percentage Amount of Cloud.												Percentage Frequency by Seasons. I. Dec.–Feb., II. Mar.–May, III. June–Aug., IV. Sept.–Nov.							
				Dec.–Feb.			Mar.–May.			June–August.			Sept.–Nov.			Clear days <2.				Cloudy days >8.			
				7 h.	14 h.	21 h.	7 h.	14 h.	21 h.	7 h.	14 h.	21 h.	7 h.	14 h.	21 h.	I.	II.	III.	IV.	I.	II.	III.	IV.
Inland or High Level Stations.			Metres.																				
Chile . . .	2	21°	4250	30	51	34	22	23	12	20	28	18	17	27	13	30	70	62	58	6	2	6	2
,, . . .	3	22-25	2273	14	13	9	11	10	5	14	16	7	10	10	5	82	86	81	87	1	1	4	0
,, . . .	8	27-35	738	22	21	9	48	42	32	62	57	50	51	45	34	66	40	30	35	4	20	34	20
,, . . .	6	33-39 [2]	126	32	23	15	58	47	37	71	61	53	56	49	36	43	23	13	21	5	20	31	20
Brazil . . .	3	5-15½	447	74	63	51	73	56	44	58	39	27	61	48	31	7	12	27	24	34	23	10	19
,, . . .	4	16-20	815	71	77	67	54	64	44	36	48	25	54	62	43	7	16	39	24	46	21	6	24
,, . . .	9	20-22	753	65	72	60	45	57	33	39	43	25	56	65	45 [1]	7	22	34	17	41	18	14	31
,, . . .	18	22-23	786	57	63	57	45	50	36	43	42	29	51	55	47 [1]	10	23	34	19	40	24	17	33
,, . . .	7	23-25½	697	70	70	65	66	56	46	63	46	38	69	62	58 [1]	7	15	22	13	44	28	25	41
Coast Stations.																							
Chile . . .	2	18½-20	7	65	40	41	67	39	43	92	59	86	88	48	75	22	22	2	5	18	22	54	42
,, . . .	2	25-27	33	74	24	46	76	37	48	80	43	61	84	40	64	18	16	11	10	16	24	35	32
,, . . .	3	30-33	34	69	29	18	67	47	38	62	52	45	65	43	36	26	24	27	28	10	28	32	25
,, . . .	6	35-38	43	34	28	22	55	53	43	61	60	50	51	46	36	55	31	22	33	10	30	36	22
,, . . .	10	38½-44	41	61	52	47	74	66	60	80	75	71	70	64	59	20	10	7	12	26	44	59	40
,, . . .	4	52½-55	10	71	73	72	73	73	59	69	69	58	70	70	60	1	4	8	4	46	36	36	70
S. Pacific . .	2	27-33½	20	66	63	50	67	68	58	71	70	62	69	64	57	6	4	2	6	22	28	37	30
Brazil . . .	5	1-4	31	61	67	53	66	69	64	42	57	48	41	58	36	3	3	6	7	26	32	10	7
,, . . .	8	5-13	42	62	55	45	64	57	50	65	61	51	58	48	39	6	7	15	12	22	20	19	9
,, . . .	8	21-25	16	63	64	70	57	58	60	57	56	57	71	69	74 [1]	12	16	23	10	41	32	33	49
,, . . .	5	25-30	16	...	...	...	...	...	...	...	...	...	...	...	...	8	12	13	9	42	35	42	53

[1] For Chile the data refer to the whole number of stations given, but in Brazil the mean amount of cloud *at the different hours* is based on a smaller number of stations. (See Table VI.) In the zones marked (1) only the stations in the state of São Paulo are utilised for cloud amount at 7, 14, and 21 hours. There are no long-period data in Brazil south of lat. 25° S. from which the seasonal normals can be computed. Short Period *annual* values are given in Table V. for a few southern stations.

[2] Six stations below 200 metres.

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TABLE V.—Mean Annual Percentage of Cloud Amount and Percentage Frequency of Clear and Cloudy Days for Stations with 2 Years' Observations only, except Bello Horizonte and Estacion Missionera which refer to 4 and 4½ Years respectively.

Stations.	State.	S. Lat.	W. Long.	Period.	Height.	Mean Annual.			Mean.	Range.	Percentage Frequency.	
											Clear days <2.	Cloudy days >8.
Brazil. Coast.					Metres.	7 h.	14 h.	21 h.				
Pará	Pará	1 27	48 29	1904–06	10	44	64	56	55	20	...	...
Cacaual Grande	,,	2 30	63 0	1915–16	20	...	...	...	47	...	17	12
Nova Cruz	Rio Grande (Norte)	6 27	35 24	1914–15	74	...	...	...	39	...	21	15
Palma	Goyaz	12 40	47 55	1916–17	2	...	...	...	45	...	30	24
Uruguayana	Rio Grande (Sul)	29 45	57 5	1915–16	76	48	48	32	43	16	41	25
Santa Maria	,, ,,	29 45	53 49	1915–16	139	56	46	40	47	16	30	24
Cachoeira	,, ,,	30 3	52 24	1915–16	60	53	45	36	45	17	37	27
Pelotus	,, ,,	31 46	52 21	1915–16	7	66	62	58	62	8	4	32
Rio Grande	,, ,,	32 2	52 9	1915–16	2	62	57	52	57	10	17	32
Jaguarão	,, ,,	32 24	53 23	1915–16	11	48	46	37	44	11	33	20
Chile. Coast.												
Rio Bueno	Chile	40 19	72 55	1915–16	58	77	64	53	65	24	7	37
Los Riscos	,,	41 13	72 41	1912, 1914	60	74	68	58	67	16	13	48
Brazil. Inland.												
Santa Luzia	Goyaz	16 30	47 45	1914–15	958	...	...	...	43	...	37	...
Pirapora	Minas Geraes	17 21	44 53	1914–15	472	48	56	40	48	16	20	21
Theophilo Ottoni	,, ,,	18 10	41 25	1914–15	305	82	58	44	61	38	7	35
Bello Horizonte	,, ,,	19 55	43 55	1912–15	857	59	62	48	56	14	13	25
Uberaba	,, ,,	19 46	47 55	1914–15	760	50	66	46	54	20	13	29
Ouro Preto	,, ,,	20 23	43 32	1914–15	1180	69	52	57	59	17	9	27
Lavras	,, ,,	21 20	45 3	1914–15	868	52	53	39	48	14	23	22
Muzambinho	,, ,,	21 18	46 33	1914–15	1046	55	62	43	53	19	22	34
Palmyra	,, ,,	21 27	43 33	1914–15	878	87	66	74	76	21	...	45
Mar de Hespanha	,, ,,	21 56	42 47	1914–15	450	70	57	46	58	24	13	29
Caxambu	,, ,,	22 12	44 58	1914–15	890	48	61	38	49	23	26	25
Theresopolis	Rio de Janeiro	22 25	43 0	1916–17	912	...	...	...	72	...	12	53
Passa Quatro	Minas Geraes	22 31	44 59	1914–15	937	56	54	40	50	16	19	22
Bandeirantes	S. Paulo	22 36	44 28	1916–17	582	...	...	...	63	...	13	40
Guapore	Rio Grande (Sul)	28 6	51 55	1915–16	450	60	50	42	51	18	...	...
Bage	,, ,,	31 20	54 7	1915–16	220	60	61	39	53	22	20	25
Chile. Inland.												
Vallenar	Chile	38 35	70 47	1915–16	379	48	10	12	23	38	47	3
Paraguay.												
Estacion Missionera *	Paraguay	23 23	58 25	1896–1901	110	51	58	36	48	22	...	...

* Data from *Anales Oficina Meteorológica Argentina*, Tomo xiv., p. 484.

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TABLE VI.—Mean Annual Cloud Amount in State of São Paulo at 7, 14, 21 h.

(For co-ordinates of stations, see Table II.)

Stations.	Height.	Period.	Years.	Mean Annual %.			Mean.	Range.
				7 h.	14 h.	21 h.		
Coast.	Metres.							
Ubatuba	10	1902–11	10	57	71	57	68	14
São Sebastio	...	1906–12	6	56	55	62	58	7
Santos	10	1902–11	10	61	64	63	63	3
Iquape	10	1902–11	10	67	57	69	64	12
Cananea	10	1902–11	10	58	61	64	61	6
Means	...	...	...	60	62	63	62	...
Inland.								
Santa Rita	600	1902–10	9	39	45	31	38	14
Franca *	996	1902–12	8	49	64	50	54	15
Riberão Preto	560	1902–11	10	55	60	41	52	19
Mattao	560	1902–11	10	56	64	43	54	21
Ibitinga	465	1902–11	10	50	55	37	47	18
Pocas de Caldas *	1186	1903–12	7	56	60	42	53	18
San Carlos	842	1902–11	10	50	65	47	54	18
Brotas	630	1902–11	10	51	57	45	51	12
Araras *	614	1902–12	8	47	57	44	49	13
São Paulo dos Agudos	602	1905–12	8	41	44	38	41	6
Rio Claro	614	1902–11	10	66	61	52	60	9
Campos Novos	487	1902–11	10	60	54	43	52	17
Braganca	840	1902–11	10	56	65	41	54	24
Bananal *	450	1902–12	4½	57	54	57	56	3
Amparo *	658	1905–12	7	45	55	40	47	15
Piracicaba	550	1903–12	10	59	61	54	58	7
Villa Jaguaribe	1580	1905–12	7	33	38	35	35	5
Campinas	665	1902–11	10	53	60	43	52	17
Botucatu	800	1902–11	10	42	45	38	42	7
Taubate	583	1902–11	10	68	59	60	62	9
Tatuhy	595	1902–11	10	50	59	41	50	18
Ytu	583	1902–11	10	48	58	38	48	20
Jacarehy	565	1902–11	10	87	63	53	68	34
S. Paulo	761	1902–11	10	76	54	56	62	22
Apiahy	885	1903–12	10	72	63	63	66	9
Means	...	...	...	55	57	45	52	...

* With interruptions.

TABLE VI. (*continued*).—Mean Annual Cloud Amount in North Brazil at 7, 14, 21 h. Based on Monthly Values sent by Dr. Morize.

Stations.	Height.	Period.	Years.	Mean Annual.			Mean.	Range.
				7 h.	14 h.	21 h.		
Coast.	Metres.							
Turyassu	15	1912–1918	7	57	80	45	61	35
Manáos	45	1912–1918	7	54	53	57	55	4
Fernando Noronha	93	1912–1917	6	55	53	43	50	12
Natal	3	1913–1917	5	60	51	48	53	12
Goyanna	14	1912–1915	4	64	...	54	...	...
Aracagú	4	1911–1916	6	60	52	36	49	24
Ondina	47	1911–1916	6	67	61	55	61	12
Inland.								
Quixeramobim	207	1912–1918	7	60	50	33	48	27
Caetité	900	1911–1916	6	72	39	35	49	37
Formosa	911	1913–1918	6	55	64	46	55	18
Catalão	875	1913–1918	6	49	63	40	51	23

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By adding together the seasonal or annual values showing the percentage frequency of clear and cloudy days the proportion of days on which the mean cloud amount varied between 2 and 8 is obtained. It is obvious that places where such days are frequent must include those in which detached clouds are common. This seems to be a point of some importance to aviators, as in some cases the mean cloud amount would appear to indicate unfavourable conditions for flying. Taking cases in which days with a mean cloud amount of between 2 and 8 formed more than 60 per cent of the whole we find that they are relatively uncommon. At high levels or inland situations in Chile only at Copiapo is this distribution frequent. It is well marked at Collahuasi in summer. Coastal stations of this type include Arica throughout the year, and the whole coast north of lat. 30° S. in summer except a patch near Iquique. In the far south Dungeness and Bahia Douglas have more than 60 per cent of such days except in summer.

In Brazilian high levels days with cloud amount between 2 and 8 are frequent over the São Paulo plateau and in Minas Geraes during the autumn and winter, and also in the states of Bahia and Goyaz at the same seasons, while in Ceará and Maranhão and on the coast from the Equator to about 14° S. lat. at all seasons of the year more than 60 per cent of the days fall between the above limits.

The special point to which attention is drawn is that bright sunshine and favourable flying conditions may be present in places where the amount of cloud *appears* large. It will be seen that at Easter Island and Juan Fernandez in the South Pacific, both of which have more than 6 units of cloudiness, there are a large percentage of days that are neither "clear" nor "cloudy." In the year ended April 1912 Easter Island, with a mean cloud amount of 66, had no less than 54 per cent of the total possible sunshine, which compares very favourably with the normals for Rome where the average cloud amount is 41 and the sunshine 56 per cent of the possible.[1] The high percentage of sunshine recorded on the north coast of Brazil where the mean cloud amount is rather high, is doubtless due to the frequency of detached clouds, and possibly also to their general thinness.

Speaking generally, it may be said that the diurnal range of cloud is much the same at all seasons of the year in Brazil and Chile (see Table IV.). At the southern Brazilian coastal stations there is, however, in summer a much reduced range due to the absence of any marked clearing of the sky in the afternoon and evening. Some individual stations, however, show marked seasonal deviations. Thus at Pará near the Equator the values are as follows:—

	7	14	21 hours.
September to January	36	66	38
February to March	78	81	78
April to August	39	57	66

The results from this station naturally draw attention to the desirability of giving cloud normals not for periods of three months as in Table IV., but for the dry and rainy seasons. Only south of the tropics do seasons as known in our latitudes exist, and even in the middle latitudes of Chile we have in reality only two seasons—the rainy from May to August, and the dry season during the rest of the year. Only in southern Brazil and southern Chile is the rainfall comparatively evenly distributed throughout the year.

It is clearly recognised that from the point of view of the physicist a great deal might have been made of the inter-relations of pressure, temperature, wind direction, and humidity at different levels, in attempting to explain the complex factors entering into the formation of cloud in the areas treated. A

[1] Instituto Meteorologico y Geofisico de Chile, Tomo 4, p. 163.

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general summary of the broad seasonal features governing atmospheric circulation would also be of interest. In the present state of South American meteorology both of these desiderata are difficult to obtain, and the present note aims at nothing more than the presentation of the available statistics compressed into such a form as may be of immediate utility to those interested in civil aviation. The printing of the tables showing the monthly cloud amount at each of the hours of observation along with the frequency of clear and cloudy days at 96 stations in Brazil and Chile would take up much space, but the data are available if desired.

In a later issue of the *Quarterly Journal* a summary of new cloud data for parts of Argentina will be given along with maps showing isonephs, etc., for those portions of the South American Continent where the stations are sufficiently numerous to justify cartographic treatment of the material, and it is hoped that it will be possible to obtain cloud values for certain areas in the Republics of Uruguay and Bolivia from which the published material is at present scanty. R. C. MOSSMAN.

EDINBURGH,
February 24, 1920.

Meteorological Work at the Radcliffe Observatory, Oxford, 1919.

The following are the chief characteristics of the weather at Oxford during the year 1919:

The mean reading of the *Barometer* (reduced to 32° F.) was 29·706 ins., which is 0·019 in. lower than the mean for the preceding 64 years. The highest reading, 30·496 ins., occurred on February 9; the lowest, 28·484 ins., on January 7.

The mean *Temperature* of the air for the year was 47°·8 F., or 1°·1 below the mean for the preceding 91 years. The maximum temperature, 85°·8, was reached on September 11; and the minimum, 15°·7, on February 9. The lowest reading of the thermometer exposed on the grass was 8°·3 on February 13.

The differences of the mean monthly temperatures from the corresponding means for the preceding 91 years are:

	°F.		°F.		°F.
January	−1·3	May	+4·7	September	0·0
February	−4·7	June	+0·5	October	−4·4
March	−2·1	July	−4·4	November	−5·0
April	−1·5	August	+2·1	December	+3·1

The number of hours of *Bright Sunshine* for the year amounted to 1568, or 94 hours above the mean for the preceding 38 years.

The monthly differences from the mean are shown in the following table:

	Hours.		Hours.		Hours.
January	0	May	+58	September	+12
February	− 3	June	+28	October	+51
March	− 1	July	−63	November	− 6
April	−31	August	+46	December	+ 3

Rainfall on the ground amounted to 26·205 ins.; this total is 0·025 in. below the average for the preceding 104 years. The number of "rain-days" (0·005 in. or more) was 171. The divergences of the monthly amounts from the corresponding mean values from the previous 104 years were:

	Ins.		Ins.		Ins.
January	+1·431	May	−1·386	September	−1·256
February	+0·531	June	−1·592	October	−1·391
March	+2·201	July	−0·193	November	−1·475
April	+0·468	August	+0·381	December	+2·256

Solar halos were observed on 101 days, parhelia being present on 15 days. The 46° halo was seen on March 2, 18 (with contact arch), November 3, and

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December 28. On 5 days parhelia were observed with no halo. Contact arches were observed on 11 days. *Sun pillars* were seen on March 15, 17, June 15, July 3, and October 21.

Lunar halos were observed on 28 nights, on one occasion (October 9) the 46° halo and paraselenæ were also seen. A *moon pillar* was seen on March 6.

The *Zodiacal light* was noted on 11 evenings between January 22 and April 23, and on 7 evenings between November 19 and December 21.

Displays of *Aurora Borealis* were noted on six nights, viz.: April 29, September 19, 20, October 1 (very bright), 17, and December 30.

Some of the chief features of the weather during the year 1919 are the following:

(1) *The Rainfall.*—The heavy precipitation in December almost exactly balanced the deficiency shown at the end of the first eleven months. The long wet season at the beginning of the year was succeeded by a longer dry one: more rain fell in the first four months (total 11·661 ins.) than in the next seven (total 10·122 ins.); the normal values for these periods being 7·030 ins. and 17·034 ins. respectively.

(2) *The Droughts.*—Absolute drought prevailed from May 13 to June 3 (22 days). Partial drought was experienced from May 7 to June 19 (44 days): and during the period July 23 to August 17 (26 days) only 0·030 in. of rain fell.

(3) *Sudden Change of Weather.*—The rapid transition from cold wintry conditions to fine, sunny weather was very marked in the beginning of May, and this was followed by frequent fine intervals until the end of autumn.

(4) *Temperatures in September, October, and November.*—The maximum temperature for the year, 85°·8, was recorded in September, on the 11th, during a hot spell of weather, which was, however, speedily followed by cooler temperatures. On the 29th of this month the grass thermometer sank to 23°·8: this thermometer also indicated frosts in the following month, October, on twenty-three nights. The mean temperature for November was 38°·0, and, with only one exception, is the lowest mean for this month recorded at the Radcliffe Observatory since the year 1828. This was November 1871 when the mean temperature for the month was 37°·6.

(5) *The Sunshine of October.*—The duration of bright sunshine (147 hours) is the greatest recorded here for the month of October since sunshine registration was commenced in 1880. The previous highest values for October were:

1917	143 hours.
1890	132 ,,
1893	130 ,,

ARTHUR A. RAMBAUT, Radcliffe Observer.

RADCLIFFE OBSERVATORY, OXFORD,
March 26, 1920.

OBITUARY.

Mr. T. W. BACKHOUSE, F.R.A.S.

At his residence at West Hendon House, Sunderland, on March 13, occurred the death of Mr. Thomas William Backhouse in his 78th year.

Mr. Backhouse came of a well-known north of England family, was born at Sunderland, educated at the Grange School and at Bootham School, York, and afterwards at the University of London.

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From early life he was greatly interested in science, particularly in astronomy and meteorology, and fitted up a moderate-sized observatory at his residence, where he carried on regular observations.

The principal results of his meteorological readings were embodied in a publication issued in 1915 entitled *Publications of West Hendon House Observatory, Sunderland*, No. 4, which gave particulars of climatic variations in Sunderland, both instrumental and non-instrumental, for a period of about 50 years. At the time of his death Mr. Backhouse had in the press an Atlas of star maps. He was also an occasional contributor of papers and notes to scientific magazines and other journals.

Mr. Backhouse was a prominent worker in social reform and greatly benefited his native town both by practical assistance and valuable advice, and will be missed by a large circle of friends and admirers.

He became a Fellow of this Society on June 15, 1892, and was elected Vice-President in 1918 and 1919.

Mr. B. H. Clarke.

Notice has been received of the death of Mr. Bruce Hammond Clarke, which occurred at Hove, Sussex, on April 16, 1920, at the early age of 28 years.

Always of precarious health, Mr. Clarke was unable to take advantage of public education and training, but his interest in science was very great and his scientific knowledge well developed. He was a Member of the British Astronomical Association, writing notes for their Journal and undertaking solar observations. Shortly before his death Mr. Clarke had contemplated engaging in statistical work on climatology for our Society.

He was elected a Fellow of this Society on March 11, 1918.

Mr. Daniel Hogarth.

Mr. D. Hogarth was born at Bentham on April 25, 1842, and died on February 3, 1919, at Sydney, New South Wales, where he had lived for about 40 years.

After the loss of the *Titanic* in April 1912 due to striking an iceberg in mid-Atlantic, he was much interested in a proposal to establish stations in the Arctic regions from which timely warning might be given of the break-up and drifting away of the ice masses, and endeavoured to get the matter taken up by the Government and the principal Atlantic Shipping Lines.

He was elected a Fellow of this Society on November 19, 1913.

Mr. W. W. Larkin.

Mr. W. W. Larkin, whose death occurred at Scarborough on December 28, 1919, at the age of 81, was borough meteorologist at that health resort for many years, taking regular observations at 9 a.m. and 9 p.m. until a short time before his death.

He was elected a Fellow of this Society on November 18, 1908.

Mr. Maxwell Hall, M.A., F.R.A.S.

The late Mr. Maxwell Hall occupied a position almost unique in Meteorology. He had so thoroughly identified himself with the meteorology of Jamaica, and had so fully discussed its weather and climate, that for years to come his name will be associated with that of the island where he did most of his life's work.

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The association of the name of Charles Meldrum with the island of Mauritius is a curiously parallel case.

Maxwell Hall was born at Cheltenham, England, in 1845. He graduated from Pembroke College, Cambridge, as a Wrangler, in 1871. The following year he settled in Jamaica. Although by profession a Barrister-at-Law, and a Resident Magistrate for a number of years, he was also an enthusiastic scientist, and erected his own astronomical and meteorological observatory at Kempshot, near Montego Bay. Here he lived and with it he became identified.

It was owing to his initiative that the Jamaica Government, in 1880, made its first annual grant of £150 towards the maintenance of a weather service, "in order to have the usual instruments read and recorded at Kingston; to encourage the registration of the rainfall throughout the Island, and to give warning of approaching hurricanes." Mr. Hall was appointed Government Meteorologist. He carried on his work with skill and enthusiasm, and himself made liberal contributions towards the support of the organisation. He enlisted the cordial co-operation of many persons, mostly planters, to record rainfall, this being economically the most important single element of the climate of the island. The records, made by means of gauges of uniform pattern, have from the beginning been sent to the office of the Government Meteorologist, who has tabulated and published them. Monthly and annual reports of the Jamaica Weather Service have been issued, and in addition to the regular observations these have contained the results of many special investigations.

In February 1899, "from the urgent necessity for economy," the Jamaica Weather Service was practically abolished, being reduced merely to the compilation of rainfall statistics. But Mr. Hall's faithful work, and his untiring interest, were not to end in failure. In 1907, on the recommendation of the then Governor, Sir Sydney Olivier, K.C.M.G., the Legislative Council voted (July 3) an annual appropriation of £150 for the restoration of the Weather Service, and Mr. Hall again took up his work as Government Meteorologist.

Maxwell Hall was an active investigator and a prolific writer. He was naturally primarily interested in the meteorology of his island, and his principal papers were in that field. Among these the more important are "The Rainfall of Jamaica" (1892; second edition, 1911) and "The Meteorology of Jamaica" (1904; second edition, 1911). To the regular *Monthly Weather Reports* of his own Service, to our *Quarterly Journal*, to *Nature*, and to the *Monthly Weather Review* (U.S.A.) he contributed notes and longer papers on a wide range of topics. Most of these are strictly meteorological; others deal with such subjects as earthquakes, tides, and sunspot periods in meteorological phenomena; while some are purely astronomical. One contribution, which is likely to be overlooked, was on "The Climate of the West Indies," published in the *Report of the International Meteorological Congress held at Chicago, Ill., August* 21-24, 1893 (Bull. 11, U.S. Weather Bureau, Pt. III., Washington, D.C., 1896, pp. 589-601).

Mr. Hall devised a method of predicting droughts in Jamaica which enabled him to forecast, a year in advance, a drought from which the island has lately been suffering. He also devised a method of predicting earthquakes in Jamaica which has shown some curious, not to say remarkable, coincidences.

Mr. Hall died suddenly at Montego Bay on February 20, 1920, "one of the most learned men of the West Indies, an active astronomer, jurist and meteorologist," as one of his American colleagues said of him a few years ago.

ROBERT DE C. WARD.

HARVARD UNIVERSITY,
CAMBRIDGE, MASS., U.S.A.,
May 12, 1920.

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Dr. G. V. Perez, M.R.C.S.

On February 29, 1920, at his residence at Santa Ursula, Teneriffe, occurred the death of Dr. George Victor Perez, at the age of 60 years.

The son of Dr. Victor Perez of Paris, and born at Teneriffe in 1860, he was educated in England, taking his M.B. London in 1883. After filling important positions in London he settled in practice in his native town of Puerto Orotava, where his services were much in demand by English and other visitors. For many years Dr. Perez took regular meteorological observations at Teneriffe. Among other writings he was the author of *Orotava as a Health Resort.* He was also greatly interested in the flora of the Canary Islands, writing many articles on the subject in different Journals. In recent years Dr. Perez was engaged upon the question of the precipitation of water from mountain mists by means of forests.

Dr. Perez was elected a Fellow of this Society on November 15, 1893.

Mr. M. R. Pryor.

By the death of Mr. Marlborough Robert Pryor, a well-known figure in both scientific and commercial circles has been removed. Born in London in 1849 and educated at Eton and Cambridge, he showed very remarkable abilities in natural science, and it was hoped by his friends that science would dominate his career. He decided, however, to enter the business world, and ultimately became a commanding figure in City life.

He was elected a Fellow of this Society on March 21, 1917, and died from heart failure at his residence at Weston, Stevenage, on April 24, 1920.

Notice has also been received of the deaths of Mr. C. H. Berners, J.P., of Wolverstone Park, Ipswich, aged 77 years, elected December 18, 1907, and Mr. William Hall, of Swerford, Enstone, Oxon, elected December 18, 1907.

REVIEWS.

Altitude and Health. By F. F. Roget, "Privat-Docent" Professor in the University of Geneva. (Three Lectures delivered in London for the Chadwick Trust, 1914.) The Chadwick Library, London (Constable & Co.), 1919. 8°. Pp. xii + 186. 12s.

Prof. Roget's book sets forth in a popular manner the effects of mountain climates upon health, especially in the Swiss Alps. The effect of altitude upon living organisms is very complex, and has by no means been worked out. Altitude means not only rarefaction of the air, but increased cold and dryness and solar radiation. What are the effects of variations in this complex upon the human body and mind, is a problem that is now occupying physiologists in relation to aviation. Their researches ought to go far to show what exactly are the reactions or responses of the organism to abrupt changes of altitude, and within what limits they can be counted upon to take place in average persons—and how apparently healthy persons differ in these respects.

Sir H. Weber used to say that the continual small oscillations of temperature from air currents in the British Islands contributed to the health and energy of the people. Island climates, with temperatures always oscillating over a small range, are described as equable in contrast to those of continents, deserts

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and mountains, which show greater extremes of temperature, both in daily and seasonal range. It is obvious that these latter must make a very different demand on the natural reactions of the body than the gently "oscillating" island climate.

The increase of solar radiation in high-level climates is more important to health than the rarefaction of the air. The figures here given, to which too much importance should not be attached, show an effective insolation of 68 per cent at sea-level, 89 per cent at 3000 m., and 94 per cent on the top of Mont Blanc. A few thousand feet bring us, especially in winter, much nearer the sun than we might suppose, because we leave behind us in the lower atmosphere the strata which intercept its rays. It follows that the air is dry. As much as half of the atmospheric moisture is, says Roget, left below us at 2000 m. Hence the beneficial effect in catarrh. The range of temperature in the mountains is increased by the warmth of the sun during the day and, when the sky is clear, by the rapid radiation of heat into space at night. But the stillness and dryness of the air, and the stimulus of the solar rays, make the body very tolerant of cold. It sounds like a paradox that we can be exposed to cold and heat at the same time, but that is actually characteristic of climates above the lower cloud belts.

It is easy to believe that the normal reactions to cold and heat in health, and the sluggish reactions of ill-health, can be powerfully stimulated by combined or alternated impressions of this kind. The climate of altitude should be considered one of the most powerful of stimulants, whilst equable climates with small oscillations are more gently stimulant and sedative. It follows that climates of this character are only suitable for healthy persons and for invalids who require *and can respond to* very brisk stimulation. This excludes at once from high altitudes large numbers of delicate people with diminished vital power, either from advancing age or chronic ailments, and for whom gently stimulating or sedative climates are desirable. No mistake is commoner or more serious than to expose those who have only a minimum of reaction power to a maximum of stimulus; and vice versa. The distinction is fundamental in medical climatology.

In his zeal for altitudes Professor Roget is not quite happy when he is referring to the British climate. He places the British Islands among the "Watered Flatlands," characterised by very great seasonal variations of temperature, "hot summers, rough cold winters," exposure to wind, humidity, and mists, and an air more charged with microbes than in the mountains. "The Flat-lands are therefore with the help of the wind just the place for the dissemination, multiplication and preservation of micro-organisms." The shallow oscillations of temperature in England have been already mentioned. The eastern and western marine climates of Britain are too little known to our Continental friends. They may also be unaware that the northern latitude gives to our moors and mountains, particularly in Scotland, a climatic character very similar to that of higher altitudes in the south. The same is true of the Baltic coasts and of the coasts and mountains of Scandinavia in the summer season. The air is pure and translucent and solar radiation at a maximum. It is true the air is not so rarefied, but that is not always a desideratum from a health point of view. There is, however, no British equivalent for the Alps in winter.

Professor Roget adds some data on the treatment of "surgical tuberculosis" at altitudes by insolation and fresh air. As good results have been claimed from sanatoria at the seaside. A large number of tuberculous prisoners of war were treated in the same way and with good results in the Rhone valley. The figures are given for 1917, showing 39 per cent "reported cured."

R. FORTESCUE FOX.

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Meteorologia Aeronautica. By GIUSEPPE CRESTANI. Milan, 1919. 16°. Pp. xv + 315, charts. Lire 8.50.

Prof. Crestani's book constitutes an excellent introduction to modern meteorology. It is more up-to-date than most elementary accounts of the subject, and can be recommended to the young student. It deals with instruments and methods of observation, the physics of many meteorological phenomena, the weather chart, and the methods of forecasting from the chart. Sections are included on the corrections to the altimeter, the methods of observing the upper wind by pilot balloons, the estimation of drift of an aeroplane, and similar subjects of aeronautical interest. Much recent information is given, and the book is written in a simple, readable style.

Nevertheless, as is almost inevitable in such first attempts to apply meteorology to aviation, the aeronautical application is not kept continuously in mind. The selection of the subjects to be dealt with, and the amount of space devoted to each subject, have been determined rather by their importance in the eyes of the pure meteorologist than by their utility in aviation. And, like all other specialists, the meteorologist is apt to be quite unduly impressed by the importance of those parts of his subject on which a great deal has been written. Thus, in regard to humidity, Prof. Crestani deals with the instruments of observation, formulae of reduction, periodic variations, etc., which have all been discussed by our ancestors; but he omits to give any information as to the conditions under which a deposition of dew on an airship may seriously impair its lift. Yet this is a matter of at least as much importance to aviators as the annual variation of mean humidity; and a simple explanation of the reason why an airship going from A to B in a clear atmosphere may become almost too heavy to fly, while one moving from B to A at the same time is left wholly free from deposit, would have more interested aviators in the science of meteorology than any of the sections on humidity in this book.

A great deal more could have been made of the subjects of turbulence, cliff-eddies, valley-winds, fogs, whirlwinds, squalls, and similar avoidable local obstacles; in connection with which practical advice, of a kind to prevent needless disasters, could easily have been included. Two out of the four sections of the book deal with the organisation of a meteorological service, and the making of forecasts from the synoptic charts. These are matters that the aviator is quite unable to control, and that are already well understood by the existing organisations. But for information that would be of practical service to the aviator in emergencies, for hints on how to use his own personal observations of cloud, wind and temperature, either to infer for himself the general conditions when he is out of touch with an organised meteorological service, or to supplement the latest official reports by deducing the subsequent changes in his own district—in short, for any application of his meteorological learning that would assist the aviator either to avoid danger or to economise fuel, we search this book, like most others, in vain. The second word of the title leads us to expect too much. J. LOGIE.

Elgie's Weather Book for the General Reader. By JOSEPH H. ELGIE. London (Wireless Press), 1920. 8°. Pp. xii + 251, pls. 8. 5s.

The author writes as a life-long nature lover, and addresses himself not so much to those who know as to those who do not know; he is careful to avoid any supposition of technical knowledge or even a hint at mathematics. His science, however, is quite sound, and as he has a very pleasant style of writing, the book will be read with interest by many who have already some knowledge of meteorology. The first chapter on the atmosphere gives a clear account in popular language of the principal phenomena at different heights according to

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our present knowledge. Mr. Elgie is a keen observer of the sky, and is perhaps at his best when he writes of clouds, thunderstorms, and the various optical phenomena, the clouds being illustrated by some of Capt. C. J. P. Cave's photographs reproduced from the Society's *Journal*. He has astronomical interests and the night sky in consequence receives full attention, but is he correct in stating that "solar halos are of much less frequency than lunar ones"? The book may be confidently recommended to the general reader.

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The diurnal (whole daily) variation of pressure (sine term) is considered at a large number of stations with reference to (*a*) latitude, (*b*) situation—oceanic, coastal, inland or mountain valley, and (*c*) season. The constants of the whole day variation are intimately related to the local conditions, especially the diurnal variation of temperature, but the following rules can be stated: (1) The phase-angle lies between 270 and 90 at 91 per cent of the stations. (2) The maximum occurs rather later near to the equator than beyond lat. 50°. (3) At oceanic islands the time of maximum is commonly about 6 a.m., and the amplitude is only about 0·4 mb. (4) At coastal and still more at continental stations the phase-angle is more irregular and averages about 120; the amplitude is much greater, exceeding 1·5 mb. in places. (5) Winter in extra-tropical and the rainy season in tropical regions approach the oceanic type; summer and the dry season approach the continental type. Hourly data for each month are set out for reference for 42 stations.

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AGRICULTURAL CLIMATOLOGY OF AUSTRALIA.

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PART I. INTRODUCTION.

§ 1. *The Climates of Australia.*—Among all the large land masses, Australia has the least average elevation and the most unbroken coastline: both of these conditions make for uniformity. But the area of the continent is very large, and it lies in one of the most variable climatic belts on the earth's surface. It would, therefore, be a serious error to judge the Australian climates only by the southern types, with which alone probably some three-quarters of Australians themselves are personally familiar.

There can be little doubt that climate is the major factor in determining the permanent settlement of the various regions of the earth. It controls agriculture and grazing, which in their turn largely determine manufacturing industries. It controls comfort and health—very potent factors in the spread of white civilisations. In fact, were it not for certain valuable mineral deposits, one would find that practically all the main centres of white settlement could be defined in terms of temperature, humidity and rainfall.

Similar controls, no doubt, operate in connection with the other races. Probably the black race flourishes within narrower limits and the yellow race within wider limits than the white race; but a very short survey will show that the Australian Commonwealth contains regions akin to those inhabited by types of each of the great races of mankind.

§ 2. *Rainfall—the Controlling Factor in Australian Settlement.*—There is no doubt that rainfall is the chief factor governing settlement in Australia even more than in most other regions of the world. The average annual rainfall map is now fairly complete (except in the central

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belt across Western Australia, where rains are very variable and records short or wanting). But the map alone gives a very incomplete statement of the value of the rains. Thus, each of the four following stations has a rainfall of about fifteen inches per year; but the settler would make a grave mistake if he assumed that the rains were all of the same type: Roebourne (lat. 21°) and Northam (lat. 32°) in Western Australia, Tennant's Creek (lat. 20°) in Northern Territory, and Cobar (lat. 32°) in Central New South Wales, have all annual totals of fifteen inches. None of these is debarred from settlement by excessive heat or dryness, but two of them will never support a large population.

The Roebourne region is marked by the most unreliable rainfall in

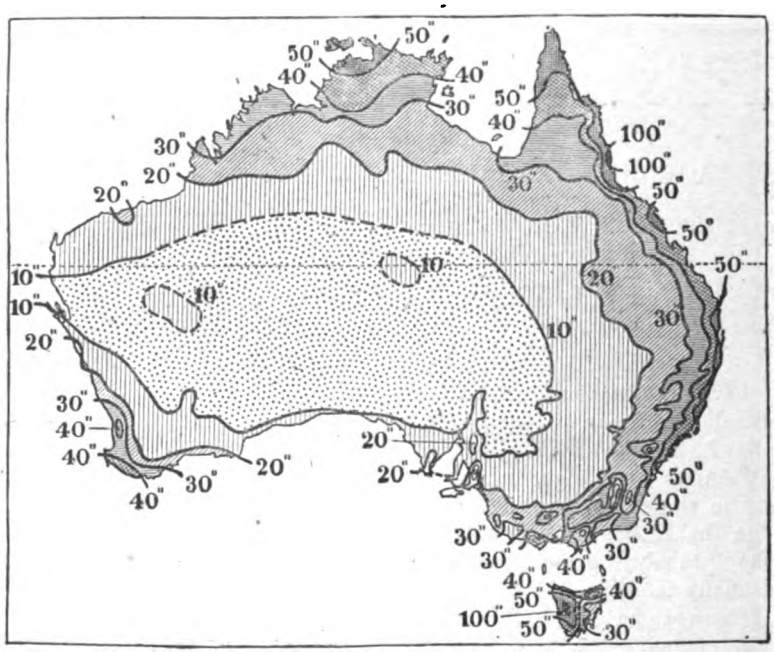

FIG. 1.—Average Annual Rainfall.[1]

Australia. In 1891 it received only 0·13 inch, while in 1900 there fell 42 inches. Tennant's Creek is chiefly characterised by a totally dry period of seven months, which extends from April to October. Cobar receives its 15-inch rainfall spread out almost uniformly through the year. Northam, Western Australia, obtains practically all of it during the wheat period, and is consequently a much more important farming region than Cobar, which is only barely within the dry-farming area.

It is, therefore, obvious that the season at which the rain occurs (see Fig. 3), and the certainty of its occurrence, are matters as important as the total amount. Hence it seems appropriate to base the configuration of the climatic regions on a consideration of these factors.

Rain Reliability.—From the previous remarks it will be seen that in some regions of Australia the rainfall is more reliable than in others—

[1] Figs. 1, 6, and 7 are reproduced by kind permission of the Delegates of the Clarendon Press, Oxford.

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quite irrespective of the total amounts. Thus, the 20 inches that the wheat farmer can expect to receive with some certainty in the Katanning district, Western Australia, is much more valuable than the twenty inches which may fall in the course of a few days at Wiluna, Western Australia.[1] To obtain the rain reliability map shown in Fig. 2, the following procedure was adopted.

A table of annual rainfalls for 20 years (1891–1910) was consulted. At each of the localities listed the departures from the normal rainfall were obtained. These departures (ignoring sign) are then averaged and the result expressed as a percentage of the total rainfall. Thus (taking a striking example), the average rainfall at Onslow, Western Australia,

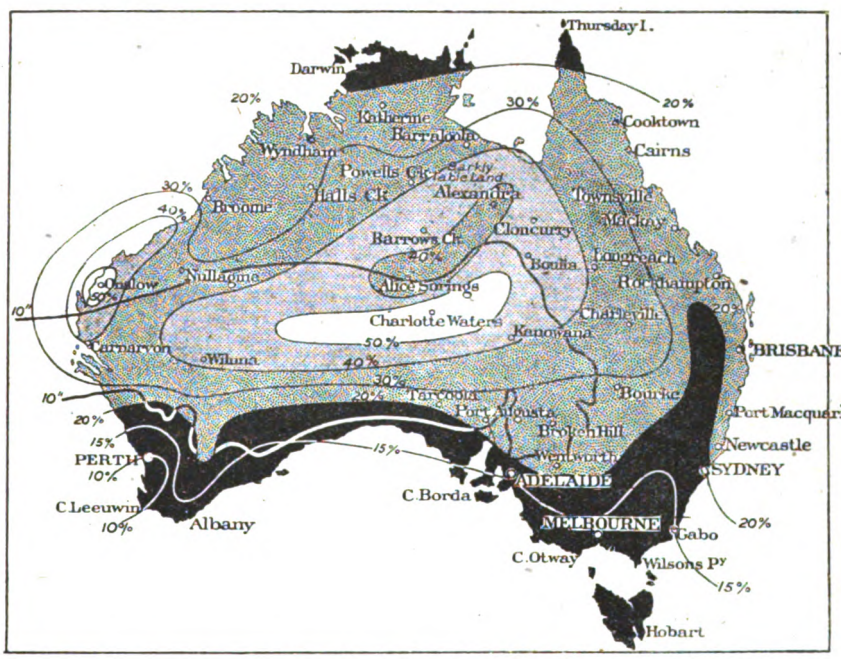

FIG. 2.—Rain reliability for Australia.

Percentages show average deviation from the mean. Most reliable—black. Least reliable—white.

(Block reproduced from the *Geographical Journal*, March 1919, by kind permission of the Royal Geographical Society.)

is about $8\frac{1}{2}$ inches, but it has varied from 1 inch in 1896 to 27 inches in 1900. The average of all such departures is 5 inches, and this is inserted on the map (as a percentage of $8\frac{1}{2}$ inches) as 60 per cent.

The map shows two "poles." Near Perth, Western Australia, is the most reliable region, where a variation of less than 10 per cent from the average is all that is likely. All along the south coast the variation is of the order of 15 per cent, and thence becomes greater as one proceeds north and north-west. The maximum variation (or least reliability) occurs at Onslow, 60 per cent, and Charlotte Waters, 57 per cent.

[1] *Vide* "Australian Environment," Griffith Taylor. Melbourne (Advisory Council of Science and Industry, Memoir I.), 1918.

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Most of the north coast shows a variation of 20 per cent, or moderate reliability, and the same is true for the east coast. A region of unexpected unreliability is the Barkly Tableland, which seems to vary by about 45 per cent. In fact, all the cooler portions of the Northern Territory have a very unreliable as well as a low rainfall, and this chart certainly indicates that agriculture without irrigation will always be a risky speculation anywhere in the inland portions of the Northern Territory and of Queensland.

It explains, also, why a low average rainfall of 10 inches in Swanland, south-west Western Australia, and Eyre's Peninsula, is able to give better crops than 10 inches in Victoria or New South Wales. It is much more to be counted on in the south-west than in the south-east.

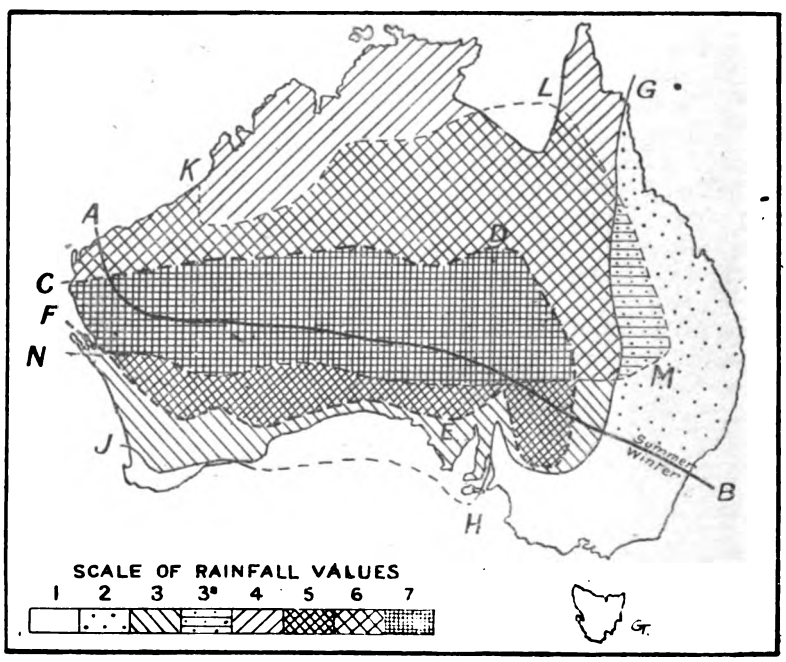

FIG. 3.—Economic Rainfall regions of Australia.

AB separates the summer from the winter rains; *GHJ* marks off the uniform rainfall region to the east and south; *CDEF* includes the area under 10 inches a year; *KLMN* includes the region of most erratic rainfall. The descending scale is explained in the table in the text.

§ 3. *Rain Regions.*[1]—Two further rain boundaries deserve discussion. The chief is of course that separating the region of winter rains from the region of summer rains. This is shown by the line *AB* in Fig. 3. The winter rains are, generally speaking, associated with the westerly winds of the Antarctic depressions. These latter lows travel eastwards along tracks which depend on the season, *i.e.* on the declination or the (apparent) track of the overhead sun. They affect Australia chiefly in winter.

In the same way the northern rains are largely due to the tropical

[1] This section is based on "Climatic Factors," *Commonwealth Year Book*, 1918.

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cyclones which hover over Northern Australia when the sun is overhead in the tropics, *i.e.* in summer. The great arid region of Australia is in the broad belt only occasionally favoured by either of these beneficial controls. This arid area extends from North-West Cape to Broken Hill, and includes 37 per cent of the area of the continent.

The dominating winds in this arid stretch have an easterly component, and, towards the north, merge of course into the permanent SE trade winds. In the interior and in the western lands it is typically a drying wind, but in the east it blows from sea to land, and contributes largely to the heavier eastern rainfall. At the same time there is a special series of tropical storms which swing down the east coast from the north in autumn and winter, and give the special character to that region.

Hence, speaking generally, there are four major rainfall regions: the summer rain region in the north, the winter rain region in the south, the uniform rain region in the east, and the arid region in the centre and middle west.

The uniform region receives over one inch per month through eight months in the year. This includes all east of the line *GHJ* in Fig. 3. It also includes almost all the timber areas in Australia, which are largely determined by the uniformity of the rain. Hence the heavy tropical rains of the Territory do not produce timber forests, for the six months' drought in winter prevents the growth of true tropical forests.

Fig. 3 shows how the rainfall varies in amount, in season, in uniformity, and in reliability. Thus, considering rainfall alone, one can usefully distinguish seven regions, which may be arranged in order of their value for settlement somewhat as in the following table:

MAJOR RAINFALL REGIONS.

Class.	Sub-Class.	Chief Localities.	Chief Products.[1]
1. Uniform . .	With winter maximum	Riverina, Victoria, Tasmania, Albany	Timber, dairies, farming, sheep, wheat, vines.
2. Do. . .	With summer maximum	Eastern Queensland, north-east of New South Wales[2]	Farms, sugar, sheep, cattle; also timber, dairies, and sugar on coast.
3. Seasonal, but reliable	Moderate winter rains	Swanland[3] . .	Wheat, sheep, vines.
4. Do. .	Summer rains .	Kimberley (W.A.) and coast-lands (N.T.)	Cattle.
5. Do. . .	Rare winter rains.	Coolgardie to Broken Hill	Sheep.
6. Erratic . .	Summer only .	Pilbarra (W.A.), Macdonnells (N.T.), Western Queensland	Sheep and cattle.
7. Do. . .	Arid . . .	Central W. Australia and inland S. Australia	Unoccupied, except for a few sheep and cattle stations.

[1] Mining settlements are ignored. [2] Type 3a (on Fig. 3) is too erratic to be classed with type 2.
[3] The temperate and well-watered south-west corner of W.A.

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§ 4. *Main Agricultural Provinces of Australia.*—Reference to the table and Fig. 3 in the preceding section will show that farming and close settlement generally are confined to the first three of the seven regions specified.

In Australia a great proportion of our wheat lands lie in regions receiving less than 20 inches per annum. Even so the farming country is a narrow coastal crescent lying in the south and east of the continent. The "crescent" is conveniently divided into several parts agreeing with the regions above. The northern tropical region comprises the Queensland littoral and reaches down nearly to the point *B* in Fig. 3. Though there is some merging in the north of New South Wales, yet on the whole there is a well-marked change in the crops when we reach central New South Wales, and this central province extends throughout the south-east of the continent as far as Eyre Peninsula in South Australia.

The temperate portion of West Australia is quite isolated geographically from the rest of Australia, and its climate and flora also differ materially. This region is conveniently known as "Swanland."

Tasmania is conveniently treated separately. Though it is geographically allied to Victoria, its climate and topography are rather different, and these have reacted on the crops and industries.

The detailed accounts of the agriculture of the Commonwealth are therefore treated under the above three divisions.

Pastoral Provinces.—Sheep and cattle are almost ubiquitous in Australia, save in the arid western interior where there is no settlement of any kind. But it is not generally realised that the great proportion of the stock is raised in the farming and wheat districts. There is a block of a million square miles (bounded approximately by the 7-inch isohyet in the south, by the 15-inch isohyet in the north, and by the 10-inch isohyet in the east) which comprises one-third of the whole area of the continent. At the end of fifty years of pastoral occupation this huge extent carries less than one per cent of the sheep and cattle of the Commonwealth, and is unfortunately of no use for agricultural occupation.

Part II. Agriculture in the East.

§ 5. *The Natural Vegetation of Australia.*—Undoubtedly the evidence of a country's possibilities for settlement which is most readily available is that furnished by the natural vegetation. It acts as an index to the soils and to the rainfall and temperature, and on these the great primary industries of agriculture and pasturage are founded.[1]

The primary division of the continent is naturally into regions watered with winter-rains and with summer-rains. This is shown by the line *AB* in Fig. 3. On each side of this line the vegetation belts are disposed somewhat symmetrically. In the centre is the almost useless sand-ridge country which extends from Wollal on the north-west coast to Ooldea on the Trans-Australian Railway. There is another smaller isolated region to the north of Lake Eyre of the same type.

[1] See the writer's paper "Settlement of Tropical Australia," *Brisbane, Queensland Geog. J.*, **32-33**, 1916-18, pp. 1-67 ; and *Geog. Rev., New York, N. Y.*, **8**, 1919, pp. 84-115.

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The major portion of the remainder of the region of very erratic rainfall is covered largely by Mulga (*Acacia sp.*) interspersed with open salt-bush areas in the south and with open grass-lands in the north. Latitude 23° seems to be the boundary between them, at any rate in the central regions, and this recalls the seasonal rainfall control distinguishing the sage-brush from the grass-land regions in U.S.A. The total number of stock grazed on this arid country is relatively small.

In the east of the erratic rainfall region, however, the grass-lands are largely developed, especially in Queensland. Here the northern plains (10 to 20 inches) are clothed with "Mitchell" and "Flinders grass," while in the south-west of the State is the "Blue-grass" (Andropogon). Here, however, are also large areas of acacia allied to Mulga, but chiefly consisting of *A. harpophylla* (Brigalow). This is abundant throughout the marches of the grass-lands and the Savannah Forest belt in the north-east.

In the south-east in this same zone (10 to 20 inches) there is some mixture of salt-bush with the grasses above enumerated. Here also there is a tendency, as the winter rains become more important, for the acacias to give place to stunted eucalypts with the Mallee habit. Here also are found outlying copses of "Colonial Pine" (*Callitris*).

Along the south this belt of low but fairly reliable winter rainfall from 10 to 20 inches was originally clothed in Mallee (*E. dumosa*, etc.), which grows in close-set stems about 10 feet high. This is often good wheat-land, and has been completely cleared in many districts.

Outside this belt comes the Savannah Forest, which is composed essentially of eucalypts growing somewhat far apart, with grass below, but very little underbrush. It is the "Parkland" type. Here are found large trees, especially along the streams, where *Eucalyptus rostrata* grows into fine specimens.

So far none of the timber is of much use except locally. As, however, the rainfall increases above 30 inches a year, there is a change in the character of the forests. True rain-forests occur, which differ in kind according to the temperature and the season of rainfall.

Thus on the east Queensland coast, where the rainfall exceeds 40 inches, we find the vine-scrubs. These extend down to Port Macquarie in New South Wales. Here the temperature is, of course, much lower, and the winter rains become more important; as a result the temperate rain forests commence with a characteristic eucalypt flora. Further south in Victoria and Tasmania with colder temperatures the Beech Forests (*Fagus*) occur.

There are none of these true forests in South Australia, but in the wetter portion of Swanland with a heavy winter rainfall is the typical sclerophyll forest of Australia.

§ 6. *Wheat.*—This crop is by far the most important in the Commonwealth, and constitutes 69 per cent of the area cultivated. Only in Queensland (26 per cent) and Tasmania (10 per cent) has it a subordinate position. The production and climatic controls in the several States are given below:

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WHEAT, 1917–18.

State.	Bushels.	Temp. Apr.–Oct.		Rainfall Apr.–Oct.	
		Whole.	Optimum.	Whole.	Optimum.
New South Wales .	37,800,000	61-52	61-52	25-9	15-11
Victoria . . .	37,700,000	55-52	55-52	25-8	15-10
S. Australia . . .	28,700,000	58-54	57-55	25-6	20-10
W. Australia . .	9,300,000	63-57	62-57	30-10	20-15
Queensland . . .	1,400,000	62-60	...	20-10	...
Tasmania . . .	250,000	52-46	...	40-10	20-15
	115,150,000				

The primary control is the rainfall, but it is not the total precipitation so much as the amount which falls during the growing period (April to October) which determines the wheat belt.

The Commonwealth Meteorologist gives the following areas as receiving over 10 inches in the period specified. I have added the areas actually cultivated.

State.	Over 10 Inches.	Area under Wheat.
	Sq. miles.	Sq. miles.
New South Wales	163,772	5,000
West Australia	93,500	2,000
Queensland	79,247	230
Victoria	74,616	4,200
South Australia	46,980	3,700
Tasmania	26,215	340
	484,330	15,470

There are obviously vast areas suitable for wheat which have not been developed. The first column, however, makes no allowance for rugged and barren regions which naturally constitute an important portion of our wetter littoral, since this includes almost all our highlands.

In the early stages of wheat-growing in Australia mistakes were made and progress was slow. Cultivation was confined to the moist coastal country with its annual rainfall of 30 to 40 inches, and wheat was not a success. The discovery that the drier districts inland were more suitable for wheat-growing altered the position very happily. The bulk of the wheat is now grown in districts with a rainfall of 25 inches and under. On well-worked *fallowed* land it is stated that splendid crops have been gathered, although the growing crop only had 2 or 3 inches of rain.[1]

In Australian wheat districts the quantity of rain is not as important as the time of the year in which it falls. Rain is wanted in the early autumn so that ploughing can be done, and in the spring when the wheat

[1] *Wheat-growing in Australia*, Melbourne, 1915.

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is heading and flowering. With rain in April and May, and again in September or October, the Australian is assured of a fine crop. The summer is usually dry and warm, and this is one of the main advantages. Unless the common rule is broken and the season is unduly wet, there is no fear of rust, and nothing to interfere with the hay-making. The main crop which is kept for grain can be left standing safely in the paddocks until it is thoroughly ripe, when it is taken off with a stripper or harvester and bagged. So the districts that have heavy summer rain are largely unsuitable for wheat-growing.[1]

If reference be made to the Rain Reliability Map (Fig. 2) it will be seen that conditions in this respect are best in Swanland (W.A.), and worst in the north of New South Wales. The former has the rainfall in winter, the best season, and though the total is low, it is reliable. The latter has most of the rain in summer, and it is also distinctly unreliable.

In most of the wheat areas the crop depends very largely on the rainfall stored in the soil from the previous year. The actual rainfall during growth may be only 7 inches or even less, but this is supplemented by the fall while the land was fallow.

In New South Wales the practice is to plough the land in July or August to a depth of from 4½ to 5 inches, and then to let it lie for six weeks, when it is harrowed. Subsequently the fallow receives frequent workings with the cultivator, so as to form a loose mulch, which checks evaporation. This operation is repeated (until sowing time in April or May) whenever a hard crust is formed. The majority of districts enjoy an annual rainfall of 20 inches or less, and it not infrequently happens that only from 6 to 8 inches of this falls during the growing period, which is, of course, quite inadequate to produce a crop of wheat of, say, 20 bushels.

In New South Wales the most productive region is the Riverina around Corowa, and thence north to Molong. The county of Hume as a whole produces 1800 bushels per square mile, and is probably the most productive centre for Australia. The relation between the wheat isopleths and the winter isohyets is extremely close. The 10-inch line is the western boundary of the wheat area except at one or two places. A rainfall of over 20 inches in the wheat period practically fixes the eastern boundary in this State, for only around Sydney is a little wheat grown in wetter districts. But until the railways are much more numerous, there will be large areas of wheat-land unoccupied. The farthest distance from the railway to make wheat-growing profitable should not exceed 18 or 20 miles.

A revolution in wheat-growing may be said to have taken place with the advent of "Federation" wheat and other new varieties produced by William Farrer. Such an extensive range is provided that farmers can now begin their sowing in the principal areas with one kind of wheat at the end of March, continue sowing through April, May, June, and finish with certain varieties at the end of July.[2] The early sown varieties ripen later, and so the harvest ripens in stages and can be more readily handled.

In Victoria the greatest area under cultivation lies in the north and

[1] *Wheat-growing in Australia*, Melbourne, 1915.
[2] *Vide* Ross, "Wheat" in *Handbook for New South Wales*.

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north-west. The irrigation counties of Rodney and Moira are the most important (though not often irrigated), but the adjoining Wimmera regions are nearly as important. These regions fall within the rainfall controls specified earlier. There are several outlying regions of considerable interest in Victoria. Thus around Sale is a small wheat district in the wet region of Gippsland, and this is due to the low rainfall of a *rain-shadow*. In the same way the rain-shadow to the south-west of Melbourne includes the drier *coastal* counties which grow wheat. In the Victorian Mallee is a large extent of sandy loam country with a light winter rainfall from 10 to 15 inches. For a long period this land was deemed unfit for wheat, but experience has proved that it is quite profitable when properly worked. There were 800,000 acres under wheat here in 1914. The land is of course worked on the 3-year rotation system of fallow, wheat, grazing.

In South Australia there is a northward bulge in the isohyets caused by the Flinders Range and possibly influenced also by the long gulfs running 200 miles into the continent. Here six counties around St. Vincent Gulf each produced more than two million bushels for the season 1915–16. The climate is ideal for wheat culture, nearly all the rain falling in winter. Hence the production per head of population is much greater in this State than any other. The county of Daly (around Wallaroo) produces nearly as much wheat (1690 bushels) per square mile as Hume in the Riverina. The 6-inch winter-rainfall line, which is about equivalent to the 10-inch annual isohyet, seems to mark the outer limit of wheat culture. This is considerably beyond "Goyder's Wheat Line" which was laid down in 1865 as a safe limit. It was based on the native vegetation.

The West Australian wheat belt is described later.

§ 7. *Dry Farming and the Limits of the Wheat Belt.*—It is very difficult to determine the lowest limit of the rainfall which admits of profitable agriculture in Australia. In much of the wheat region only one-third of the area is under wheat at a time; and the dry-farming methods of fallowing and careful tilth become increasingly important as the arid interior is approached.

Although the wheat belt lies in a region of winter rainfall (except in the north-east), there is no portion of Australia without an appreciable summer rainfall. Thus even in the Northam region (W.A.) the five hottest months contribute 3 inches out of the total 17. Hence the statement that "all the rain falls at the right season" is only relatively correct.

The definition of dry farming varies in the district concerned. Thus in South Australia a region receiving less than 18 inches a year is so classed, but in northern New South Wales 22 inches or even 25 inches is "dry." In Victoria wheat is grown in the Mallee country between Ouyen and Pinneroo, with an average of 13 inches of rainfall.

A factor of vital importance in dry farming is the evaporation. In Australia (as in most parts of the world) only a few stations have records of this element, and some of the records in the west especially are obtained from small pans which are not satisfactory. It has been stated that every 3 inches of evaporation demands 1 inch of extra rain as an offset, so that it is found that 15 inches of rain in the south-west of

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New South Wales is equivalent to 20 inches in the north-west.[1] I give the *net* rainfall (rainfall minus evaporation), as nearly as our records will admit, in Fig. 4. It is to be noted that a worked summer fallow accumulates 5½ to 7 inches more water (in the upper 6 feet) than similar soil growing a crop. (Anderson, *loc. cit.*)

The typical dry-farming region in South Australia for profitable wheat is the Mallee—of which Lameroo may be taken as a type. But here 16 inches is the average. The land, however, was locally termed "desert" until about 1896. It consists of light, sandy ridges running east and west, which are about ¼ mile wide. Dark loamy hollows alternate with the sand-ridges. Mallee scrub (6 to 15 ft. high) covers

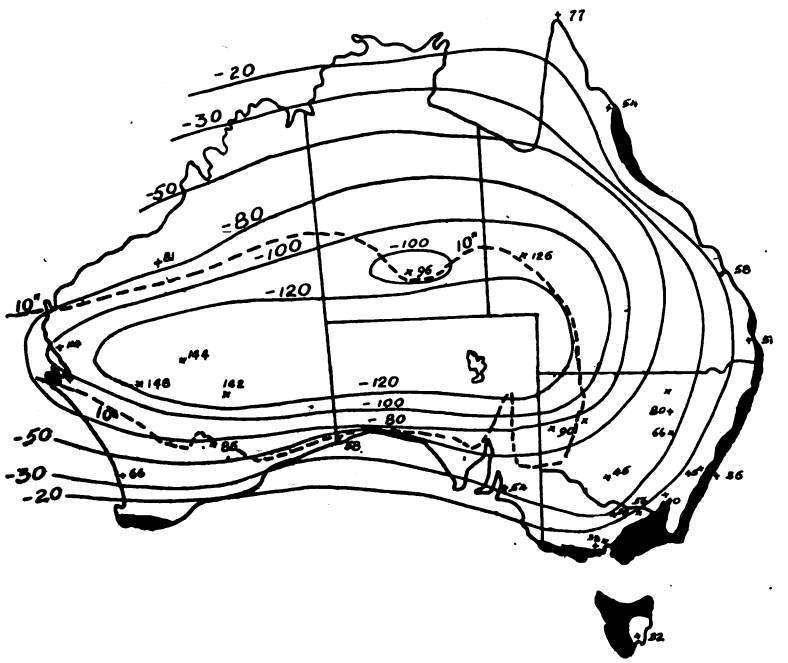

FIG. 4.—Sketch Map showing net Rainfall (rainfall – evaporation).
Small figures are inches evaporated per annum.
Black areas are those where rainfall exceeds evaporation.

most of the country. This is rolled down in June and July, and then burned. The seed is sometimes merely drilled in, no ploughing being attempted. With the aid of superphosphates crops of 13 bushels are not uncommon, though 8 has been the average to date.

The writer in his Bulletin on Climatic Control[2] showed that a close parallel existed between the conditions in east-central Queensland (between Mackay and Charleville) and in central India. At Jabalpur in India the temperatures are much higher than those of the Queensland wheat belt, yet great quantities of wheat are grown.

§ 8. *Oats.*—This grain only represents 5 per cent of the area under

[1] Anderson, *Dry Farming Conference, Adelaide*, 1911.
[2] *Melbourne, Commonwealth Bureau of Meteorology*, Bull. No. 14, 1916.

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crop in the Commonwealth. Victoria has produced 55 per cent of the total, which of late years has amounted to about 15 million bushels. Tasmania is the next State, while South and West Australia are nearly as important. Much is used as hay.

The distribution of the main crop differs considerably from that of wheat (see Fig. 5). The chief region is in the Central District around Melbourne (Jan. 67°·5, July 48°·4), while the Wimmera region ranks next

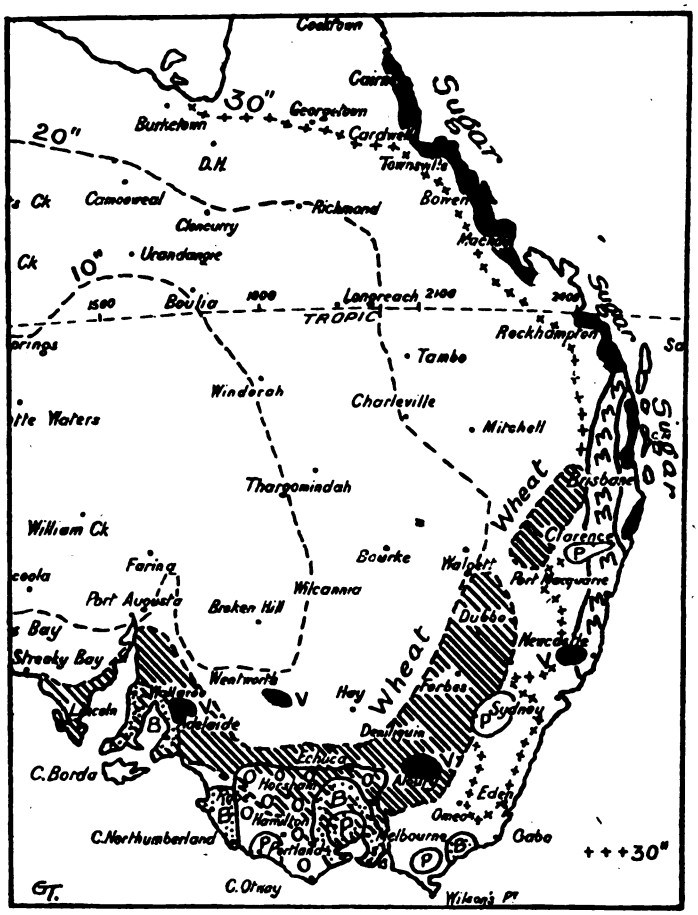

FIG. 5.—The chief Crops in Eastern Australia, showing optimum regions only. B = Barley, M = Maize, O = Oats, P = Potatoes, V = Vines. Three main isohyets are indicated.

in importance. Hence the temperature is 5° cooler than that for the chief wheat district, while the rainfall is several inches heavier, and the evaporation 5 inches less. The whole of Victoria—excluding the Mallee, the mountainous east and Gippsland—is, however, very largely interested in the oat crop.

In the other States the limits are much the same as for wheat, save that a fair crop is grown along the cool wet south coast of New South Wales, where hardly any wheat is found. The most northern crop is in

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Queensland around Gayndah, where the average annual temperature is 70°. Most of the northern oat crop is, however, used as hay or green fodder.

§ 9. *Sugar.*—This crop is confined to the well-watered east coast. The sugar is all derived from cane, apart from a little sugar-beet grown in Victoria. The cane plantations extend down the east Queensland coast and into New South Wales. The range of temperature is very considerable, ranging from 78° F. at Port Douglas to 68° F. at Grafton. The necessity for a rainfall exceeding 40 inches confines the plantations to the coast (see Fig. 5).

The following table shows the climatic controls of the chief cane fields.

Latitude.	Locality.	Approximate Temperature.	Annual Rainfall.	Area of Sugar, 1917.	Order.
°S.		°F.	ins.	Acres.	
16	Douglas	78	83	24,000	4
17	Cairns	76	90		
17½	Mourilyan	76	159	34,000	2
18½	Ingham	76	80		
19	Townsville	76	50	22,000	5
19½	Ayr	75	45		
20½	Proserpine	75	42	6,000	8
21	Mackay	72	68	42,000	1
24	Gladstone	71	41	600	11
25	Bundaberg	70	44	25,000	3
25½	Childers	70	42	18,000	6
26½	Maroochy	69	65	2,000	9
27½	Rosewood, etc.	69	32	2,000	10
28	Nerang	69	58	400	12
29	Lismore	68	70	11,000	7
30	Maclean	68	47		

In Queensland, sugar-cane comprises one-third of the agriculture of the State (about the same as maize), and is worth more than three millions sterling annually. There are forty-two mills—the tendency being to shut down the small mills and build fewer but much larger mills.

The plantations are confined to the narrow belt between the highlands and the sea. Here are the constant trade winds, and numerous coastal cyclones give an abundance of rain. The most progressive region is that near Mourilyan, which has the highest annual rainfall in Australia (Harvey Creek, 165 inches). The plantations are made in two types of country, the vine scrubs and the eucalypt forest. The former is a true Malayan tropical forest with many softwoods; the latter the more open type without vines, and containing much "bloodwood."

It is stated that the northern canes yield more sugar than the southern. Thus in the Cairns district 8 tons of cane give 1 ton of sugar, while in the extreme south 10 tons are required. Intermediate regions vary correspondingly.

The industry is of great interest, as the white cane growers near Cairns are the advance guard of such agriculture in the tropics. (For instance, the coastlands of Texas have a mean temperature like that of Bundaberg (70°), while Rio de Janeiro resembles Ayr (Q.).) I know of no white farmers outside Queensland who work in lat. 16° at sea-level with temperatures such as occur at Port Douglas.

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Cane-cutting is done chiefly in June and the following cooler months. It is stated that the death-rate is low, even among children. This district is fortunate in having the Atherton tableland, 2000-5000 feet above M.S.L., immediately behind it, in which the coastal settlers should be able to recuperate. The rainfall is sufficient in most of the plantations, except in the Bundaberg and Ayr districts. Here irrigation is resorted to.

In New South Wales the sugar crop is less than ½ per cent of the total crops. It has gradually been driven north by fear of frost, and is now confined to the Grafton-Lismore region in the extreme north. Here dairying is displacing sugar, so that the crop now is only one-third of what it was in 1895. There are only three mills in the region.

§ 10. *Maize.*—The crop for Australia is about 8½ million bushels. It is very much less important than the wheat crop—except in Queensland, where the total is three times as large. About 93 per cent of the whole is grown in Queensland and New South Wales. The chief areas extend southward from Bundaberg through Nanango and the Darling Downs, and thence to the coast from Grafton to Newcastle (see Fig. 5). Almost the whole crop grows in the littoral to the east of longitude 150°. Hence it requires for best results a rainfall exceeding 25 inches, and a temperature not less than that of Sydney (January 72°, July 52°).

There is also a flourishing crop on the tropical Atherton tableland behind Cairns in Queensland, and indeed it extends in patches right through the sugar region.

Maize is also grown in smaller quantities in the southern States, especially in eastern Gippsland (Vic.).

§ 11. *Barley.*—The crop is about four million bushels, and is grown chiefly in South Australia and Victoria, which contribute 85 per cent of the whole. The average yield is about 18 bushels per acre, of which the greater portion is used for malting. The crop is grown chiefly in the wetter and cooler portions of the wheat belt.

In South Australia, Yorke's Peninsula and the Gambier region are the chief centres (see Fig. 5). In Victoria the central belt southward from Echuca (especially around Werribee) is the chief source. In New South Wales a small supply is grown on the cooler, wetter portion of the western slopes of the highlands, and in the Riverina.

§ 12. *Vineyards and Orchards.*—These are naturally confined to the well-watered portions of the Commonwealth (see Fig. 5).

South Australia and Victoria contain 80 per cent of the vineyards. We see a disconnected belt of vineyard country from Clare in South Australia to Maitland in New South Wales. These localities all lie between the 65° F. and 55° F. annual isotherms, and (excluding irrigation settlement) are all between the 20- and 30-inch annual isohyets. Hence the climatic controls are very well marked.

Orchards are (proportionately to population) most important in Tasmania and in West Australia, and are discussed in the sections devoted to those regions. But Victoria and New South Wales have larger aggregate areas. In New South Wales oranges come first, being grown chiefly within fifty miles of Sydney or on the north coast, and in the irrigation region near Narandera. Peaches and apples are also important, and are obtained in much the same districts.

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In Victoria, peaches, apples, and pears are the chief fruits. They are grown within 50 miles of Melbourne or in the irrigation regions around Shepparton in the north. Tropical fruits such as the banana and pine-apple are grown extensively on the Queensland coast, especially around Maroochy, 60 miles north of Brisbane. Pawpaws, mangoes, and all similar products, of course, grow readily in the northern sugar districts.

§ 13. *Hay.*—The Commonwealth Year Book states: "Next in importance (to wheat) is the hay crop, which for the five seasons ended 1916–17 averaged nearly 19 per cent of the area under crop. In most European countries the hay crop consists almost entirely of meadow and other grasses, whilst in Australia a very large proportion of the area under hay comprises cereal crops, mainly wheat and oats. Marked fluctuations occur in the areas from year to year, due principally to the variations in the relative prices of grain and hay, and the favourableness or otherwise of the season for a grain crop. Thus crops originally sown for grain are frequently cut for hay, owing to the fact that the outlook for the due development of the grain is not satisfactory." For instance, in the drought year 1914 nearly one million acres were cut for hay in New South Wales instead of the normal 150,000 acres.

The hay crop is obviously determined by the same climatic controls as the grain crop. In New South Wales, South Australia, and West Australia, wheaten hay is by far the chief product. In Victoria, with a cooler climate, oaten hay is three times as important. In hotter South Queensland oats and wheat are about equally important, but the lucerne crop is greater than both together.

Considerable areas in the dairy districts have been sown with foreign grasses, especially along the coast of New South Wales. But it must be remembered of the native Australian grass, that, long after it has passed maturity and is bleached and withered on the roots, it is excellent fodder equal to hay conserved in the ordinary way.

§ 14. *Potatoes.*—Eighty per cent of the potatoes are grown in the three States of Victoria (52 per cent), Tasmania (18 per cent), and New South Wales (12 per cent). In the former State the three metropolitan counties with West Gippsland and the Warrnambool region account for nearly the whole crop. Obviously proximity to Melbourne is a determining factor, for there are many square miles of similar country along the coast which are quite as suitable but are not yet utilised for intensive farming.

In New South Wales the chief crop is grown on the slopes west of Bathurst and Goulburn, and on the northern tableland and Glen Innes. These regions all have about 30 inches of rain yearly. The coastal crop has fallen off through blight, though many tons are still grown near Grafton in the north-east corner, which has 40 inches of rain.

§ 15. *Irrigation.*—It is natural in a dry continent like Australia that much attention has been given to irrigation. Out of the total 2,974,000 square miles no less than 1,697,911 have less than 15 inches of rainfall. It is true that wheat has been grown within this isohyet on one or two narrow strips in the south, but on the other hand huge areas in the north, owing to the enormous evaporation, are useless for agriculture even with a much greater rainfall. Probably we shall not be far wrong if we

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take 13 inches in the south, 18 inches in the south-east, and 25 inches in the north and north-east as bounding the areas where profitable and *reliable* agriculture is possible without irrigation. This leaves over two million square miles which cannot be adequately developed without extra water.

If I dwell on this topic it is because such absurdly optimistic statements as to settlement in the interior and northern coastlands are still being disseminated in the press.

While it is admitted that irrigation is only in a youthful stage in Australia, the total amount so benefited is infinitesimal (6 parts in 10,000) compared with the vast areas requiring water, and unfortunately it must ever remain so.

IRRIGATED LANDS IN AUSTRALIA, 1915.

State.	Under 15 Inches.	Approximate Irrigated Areas.
	Square miles.	Square miles.
New South Wales . .	122,265	400
Victoria	19,912	600
South Australia . . .	351,005	10
West Australia . . .	746,468	6
Remainder	458,261	0
Totals . . .	1,697,911	1,016

The irrigation settlements are almost wholly confined to the valleys of the Murray and Murrumbidgee. The older settlements are along the Murray, as at Renmark (S.A.) and Mildura (Vic.). At Renmark 5000 acres are irrigated, and produce sultanas, oranges, apricots, olive oil, etc. Numerous smaller settlements are being irrigated lower down the Murray at Waikerie, Moorook, Berri, and Cadell. These places have a rainfall of 10 to 12 inches a year.

At Mildura work was started in 1887, and now 12,000 acres are under intense culture, vines predominating. The site was originally a sheep run and carried one sheep to every thirty acres, yet here in 1916 the dried fruit harvest was worth £683,000. The rainfall is 10·8 inches.

The Goulburn River scheme is the largest in Victoria. It serves, either for irrigation or domestic and stock purposes, 850,000 acres of land in the valleys of the Goulburn, Campaspe, and Loddon Rivers. A main reservoir on the Goulburn River stores 197,000 acre-feet, and supplies farms at Shepparton (rainfall 18 inches), Rodney, Stanhope, Tongala, Deakin, Rochester (16 inches), and Tragowel (13·2 inches). The farms average about 60 acres each, and during the past eight years 1209 new settlers have established prosperous homes. Dairying, orchards, lucerne and vegetable growing are the chief industries.

In the Wimmera and Mallee is an important series of Water Trusts. These supply water for stock and domestic uses (but not for irrigation in general) from reservoirs near Stawell (20 inches) to drier wheat and pastoral districts to the north, such as Hopetoun (12 inches), Warracknabeal (15 inches), Wycheproof (14 inches), etc.

The Murrumbidgee scheme in New South Wales is the most ambitious in Australia. At Burrinjuck (near Canberra) is a dam 240 ft.

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high across the deep river gorge. It impounds a lake 40 miles long holding 33,612 million cub. ft. The water runs from the reservoir to Berembed, 200 miles down the river, and here is diverted to the Yanco and Mirrool areas north of Narandera. The rainfall on the latter areas is about 16 inches. The cost of water is about five shillings per acre-foot. The average "all-irrigable" farm is about 50 acres. It is estimated that ultimately there will be 6000 farms and 100,000 people in these areas. Fruits, vines, vegetables, and fodder are being grown, and dairying and pig-raising are progressing. Butter and cheese factories are in operation, and two new townships—Leeton and Griffith—have come into being.

There are other small settlements near Wentworth and Hay, and many projects with regard to the northern and coastal rivers of the State are being considered. A gigantic scheme is in progress to dam the Murray near Albury, which will regulate the flow at all times. It will prevent the recurrence of adverse conditions such as in 1914, when the Murray ceased to flow for the first time in history.

§ 16. *Artesian Water.*—There are several artesian basins in Australia giving a water supply which has been invaluable for stock—though it has not affected agriculture in any important degree. The largest is the great Australia basin which covers the south-west half of Queensland and parts of the adjoining States. Its area is about 569,000 sq. miles. The Murray River basin includes the lower portions of the main tributaries, and covers about 100,000 sq. miles. The other basins, such as that near Eucla and in the north-west, are not of much importance as yet.

Part III.—Pastoral Industry in the Eastern Division.

§ 17. *Sheep.*—Ninety per cent of the sheep of Australia are found in the south-eastern third of the continent, *i.e.* east of a line joining Townsville to the Bight. (See Fig. 6.) Since the climate is not very

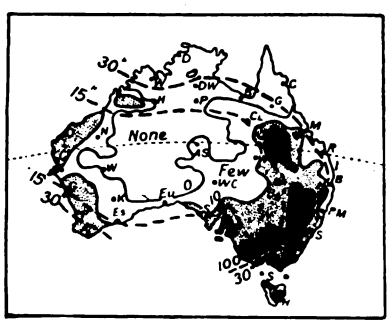

Fig. 6.—Control of the Sheep Industry by the 15- and 30-inch isohyets.
Black areas, over 100 sheep per square mile. Dotted areas, over 10.

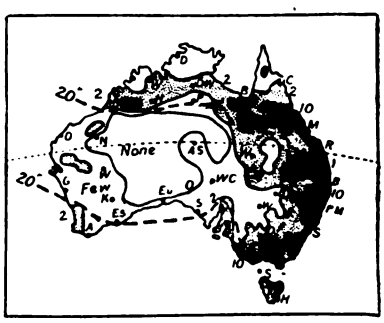

Fig. 7.—Control of the Cattle Industry by the Rainfall.
All the chief areas receive more than 20 inches per annum. Black areas have more than 10 cattle per square mile. Dotted areas have more than 2.

different in some of the coastal regions of the western portions of Australia, we realise that there is ample room for a vast increase in the number of sheep grazed.

The major control is obviously the total rainfall. The numbers

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grazed in the region receiving less than 10 inches are insignificant. Of great importance as indirectly defining the northern limit is temperature —for there are practically no sheep in the region with an average temperature exceeding 77° F., except for a quarter million along the north-west littoral. Sheep seem, however, to flourish at all temperatures lower than this from Richmond (Q.) with 76° to Hobart (Tas.) with 54°.

Premising that the sheep country is not fully exploited in the north and west, we may tabulate the controls somewhat as follows:

State.	Millions in 1916.	Rain Control.		Chief Districts.
		Optimum.	Total Range.	
		ins.		
New South Wales .	36	20-30	10-40	Moree, Young, and Riverina.
Queensland . .	16	15-20	10-30	Longreach and Darling Downs.
Victoria . . .	13	20-30	10-50	Hamilton and Ballarat.
Other States . .	12	20-30	8-60	Mt. Gambier (S.A.), Longford (T.).
Total . . .	77			

The great drought culminating in 1902 (when the sheep country in southern New South Wales received 9 inches instead of the normal 17 inches) resulted in a decrease of the total number from 95 millions to 55 millions. With each succeeding drought it is probable that these losses will be greatly minimised. Thus around 1914 another series of bad seasons reduced them from 93 millions to 69 millions. As more railways are built it will be possible to move the sheep to coastal regions where feed is usually available, and the tremendous losses of the past will not recur.

The close relation between the distribution of sheep and of rainfall is brought out by the following table, which represents the conditions on an east to west section across New South Wales in a somewhat generalised fashion. It is to be noted that the densities are not for fully stocked country, but include the *whole area* of each of the counties involved in the census.

Annual Rainfall in inches.	Sheep per sq. mile.	Representative District.	
8	20 (?)	Milparinka,	Wholly sheep.
10	70	Wilcannia,	
15	100	Hillston,	
20	180	Forbes,	Farming country.
25	250	Young,	
30	350	Tamworth,	
35	400	Armidale,	
40	100	Goulburn,	
45	None.	Few on South Coast,	Dairy country.
50	None.	Too wet,	

Based on Fig. 14 in the writer's Bulletin "Climate and Production," 1916.

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In this State the sheep in the eastern highlands are largely Lincolns, Leicesters, and other long-wool breeds. The drier western slopes and western plains are devoted to the Merino.

In arid Australia there are sheep doing well on country with less than 10 inches of rainfall, *i.e.* near Carnarvon. With well-sinking and dams there is a future in the southern arid districts for large holdings, which alone can give sufficient acreage to each individual sheep. In similar country in New South Wales it was found that six acres would carry one sheep,[1] but the rabbit plague and recent dry seasons have made much larger areas necessary.

§ 18. *Cattle.*—This industry is not nearly so important as the sheep industry. Although in many of the cooler regions where sheep are reared, cattle also graze, yet the latter are found to thrive in wetter country than sheep. As a rule the wetter districts in the east and north are the strongholds of cattle, though they have been to a certain extent replaced by sheep in many of the more closely settled southern localities. In some of the drier regions, however, the converse is taking place—largely owing to the dingo pest. Country in arid South Australia and Queensland was found suitable for sheep, but of late years has been converted into less valuable cattle runs. Moreover, where permanent water is scarce, cattle can cover a greater range of ground, and so in the driest and more remote stations cattle are almost invariably grazed.

By far the greater number are reared in the eastern coastal belt. (See Fig. 6.) In the three eastern States the cattle occur almost wholly in the wetter region outside the 20-inch isohyet. Assuming that the newer northern and western regions will progress along similar lines in the future, then a glance at the rainfall map shows that the chief advance will be made in Kimberley (W.A.) and Northern Territory. The greater part of Western Australia and Southern Australia has no large areas of unoccupied land with the above favourable rainfall, and must necessarily advance much more slowly than the two regions specified.

CATTLE AND RAINFALL IN AUSTRALIA IN 1912.[1]

State.	Cattle.	Percentage of Australia.	Area with Rainfall over 20 inches.		Dairy.	Percentage of Australia.	Optimum Rainfall in inches.
			Tropical.	Temperate.			
Queensland .	5,210,891	45·0	313,183	80,000	375,660	7·2	40+
New South Wales	3,033,726	26·2	...	130,468	852,040	28·0	40+
Victoria . .	1,508,089	13·0	...	55,346	655,939	44·0	30+
West Australia .	806,294	7·0	102,606	36,924	27,310	3·0	20
N. Territory .	405,552	3·5	180,940	...	300	...	20
South Australia	383,418	3·3	,,	14,875	114,734	33·6	20+
Tasmania . .	222,181	2·0	...	25,278	60,160	27·0	30+
Total . .	11,577,259	...	...	...	2,086,885	...	...

[1] Cattle in 1916 totalled 10,459,237, *i.e.* somewhat less than in 1912.

[1] *Pastoral Review, Melbourne*, October 1919.

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All the country with more than 10 inches of rain has some cattle, though naturally where the more profitable industries of wheat and sheep prosper, as in western New South Wales, Central Queensland, Swanland (W.A.), etc., they are relatively unimportant.

The table on preceding page shows at a glance the relative importance of the States, the number of cattle reared for dairy purposes, the areas of well-watered country, and the optimum rain control.

In Queensland the densest cattle district is naturally devoted to dairies and is found in the south-east corner. Rockhampton and Townsville are also important districts, but the majority of the beef cattle come from inland, either the downs and plains along the northern (Cloncurry[1]-Townsville) railway, or along the (southern) Charleville-Brisbane railway. Devons, Shorthorns, and Herefords are the more common breeds. On the other hand, the central railway is largely devoted to sheep.

Although Northern Territory contains less than 4 per cent of the cattle of Australia, yet this is the only important industry in that huge region. Cattle are reared chiefly on a belt including the Victoria River Basin and the Barkly Tableland. This belt receives about 20 inches of rainfall per year, and has an average temperature of 80°. This determines the presence of extensive well-grassed prairies between the arid Mulga (*Acacia*) country to the south and the ranker vegetation of the north. Victoria River has about 300,000 cattle and Barkly Tableland some 100,000. Extensive freezing works are in operation at Darwin.

Somewhat similar climatic controls obtain in the Kimberley region of tropical West Australia. Here along the Fitzroy River are vast plains covered with rich grass, and large areas maintain 20 cattle to the square mile, giving a total of about 600,000 head.

§ 19. *Dairy-farming.*—Three-quarters of the dairying is carried on in the States of New South Wales and Victoria. Cattle bred for dairy purposes need milder climatic conditions than those reared for beef only, so that the chief dairy regions are along or near the coasts.

In New South Wales the centre of the industry has migrated from the south coast to the north coast, where land is cheaper and the rainfall in general heavier than in the original centre of dairying in the Illawarra district.

Along the coast the rainfall is uniform and reliable. Here also the evaporation is less than the rainfall, and hence the vegetation keeps green all the year round. There is, however, a great deal of milk and butter produced at some distance from the coast by farmers who combine dairying with wheat-growing or mutton-raising.

Seventy-five per cent of the milch cows in the State are in the coastal region, and no less than 277,000 (half of the whole number) are found on the north coast. Over one million acres are under sown grasses along the coast, and in the colder southern dairy districts a great deal of ensilage is prepared.

Victoria, however, led the way in dairying, and here it occupies a larger proportion of the State than in New South Wales. For the most part the cows are fed solely on natural pastures, but progressive farmers

[1] Cloncurry: Jan. temperature 87°·3, July 61°·5, annual 77°·1 F.

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find it pays them to grow fodder for their herd and to shelter the animals in the winter.

Two-thirds of the dairy cows are kept in the Western District and in Gippsland. The former is famed for its rich volcanic soils, and almost every town and hamlet has its butter factory. The rainfall varies from 25 to 30 inches. In Gippsland the rainfall is heavier, from 25 to 40 inches, and large areas were covered by heavy forest, but this is giving place to dairy farms, so that practically every railway station has become a centre of the industry. Owing to its suitable climate much maize is grown, and much of this crop reaches the market in the form of butter and pork.

Queensland is rapidly progressing as a dairy country, especially the south coast and Darling Downs; while in South Australia the dairies spread from Port Germein (near the head of the Gulf), with a rainfall of only 13 inches, down to Mt. Gambier in the extreme south, with a rainfall of 32 inches.

§ 20. *Arid Pastoral Country.*—While it is true that a very great proportion of the stock is grazed in the wetter regions, yet considerable progress has been made in part of the really arid region. One of the most prosperous of the "desert" pastoral properties is situated 40 miles west of Broken Hill, and conditions here will indicate how much can be done with capital and initiative.[1]

At Mutooroo the average annual rainfall is only 7½ inches, and the rain falls in almost any month of the year; while the evaporation is 90 inches. The "run" covers 3000 square miles, and was originally waterless, *i.e.* containing no rivers, artesian or shallow supplies, except four small wells. It is an open salt-bush (*Atriplex*) plain with a proportion of "scrub."

It now carries 33 sheep to the square mile, and this has been rendered possible by the excavation of 200 "tanks" costing over £100,000. Some of these tanks are huge excavations 100 yards long, 80 yards wide, and 25 feet deep. They collect surface water after the infrequent rains, which is then pumped to the 600 paddocks into which the run is subdivided. It is obvious that many years of effort and an enormous outlay are necessary before such country can be profitably exploited. But the huge unoccupied areas in the south with similar climatic conditions make the lesson an invaluable one. It is to be noted that in the northern arid regions a very much higher rainfall (about 14 inches) would seem to be necessary to obtain equivalent results, owing to the much greater evaporation and long winter-drought season.

§ 21. *Drought.*—In more than one-third of Australia drought is a permanent condition, while exactly one-half of Australia receives practically no rain for six months of the year. It is, however, the borderlands between these arid regions and the well-watered districts where King Drought is most feared. For here grows our main wheat crop, and here are situated our chief stock regions.

As regards the inland portion of South Australia, Victoria, and New South Wales, very dry conditions or true droughts have occurred about once every three years. Quayle[2] cites the following (since 1880)—

[1] *The Australasian*, 1919 (p. 1082).

[2] *The Climate and Weather of Australia.* By H. A. Hunt, Griffith Taylor, and E. T. Quayle. Melbourne, 1913.

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1881, 1884, 1885, **1888**, 1895, 1896, 1897, 1899, **1902**, 1907, and 1911. We may add the disastrous years of **1914** and 1919. Of these 1885 was bad only in South Australia, and 1911 had good rains in the least useful season (summer), while 1919 was worst in the Darling basin.

There are two main types of drought years, shown especially well in 1888 and 1902, according to Mr. Quayle. In both types the barometric pressure is much above normal.

VERY DRY YEARS SINCE 1885. (INLAND S.E. AUSTRALIA.)

Type.	Other Years.	Highs.	Lows.	Remarks.
A. Like 1888	1895 1907 (1914) 1919	Strongly developed, somewhat northern tracks, and no digressions.	Antarctics on normal tracks, but no tropical cyclones.	General lack of humidity.
B. Like 1902	1896 1897 1899 1911 1914	Often located over S.E. Australia for long intervals.	Intense Lows often located over Tasman Sea. Feeble over Australia.	Rain-storms deflected too far south.

PART IV.

§ 22. *The Swanland Region.*—This convenient term designates the temperate region in Western Australia with a rainfall exceeding 10 inches per annum. The south-west corner of Australia differs materially from any other portion of the continent. It is isolated by a tremendous stretch of arid country (some 600 miles) from the wheat regions of South Australia. The region to the north and east receives less than 10 inches of rainfall, while the evaporation is over 100 inches per annum. On the west and south it is bounded by the ocean, and until the recent

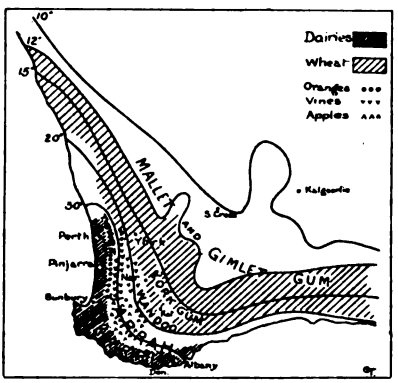

FIG. 8.—The Rainfall Control of Vegetation and Crops in Swanland, Western Australia.

Trans-Australian Railway was completed (November 1917) all communication with the rest of Australia was by sea (see Fig. 8).

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It differs climatically from all except perhaps Eyre Peninsula (S.A.) in the season of its rain, which occurs principally from May to October. Moreover, the rain is derived from Antarctics and coastal Lows much less than from the tropical loops and troughs which largely supply the Adelaide region. The natural vegetation is also markedly different from that of the rest of Australia, indicating that this isolation dates back to Tertiary times.

Few regions in the world exhibit rainfall controls so clearly—whether we consider the forest belts or the industries which are displacing them. The isohyets run parallel to the coast-bounding L-shaped strips. Thus from Perth round Cape Leeuwin to Albany is a strip 40 miles wide receiving more than 30 inches per annum. This was clothed with splendid eucalypt trees of three species—"Tuart" (*E. gomphocephala*) in the north, "Jarrah" (*E. marginata*) in the centre, and "Karri" (*E. diversicolor*) in the south, especially where the rainfall increases to 40 inches. The next strip, from 30 to 25 inches, was mapped botanically by a continuous belt of Jarrah, and the next (25 to 20) still farther east by a belt of "Wandoo" (*E. redunca*). From 20 to 15 inches is the habitat of the York gum (*E. loxophleba*). Here also are found specimens of Mallet, Salmon, and Gimlet gums, which are small trees, but invaluable for mining timbers. These latter grow throughout the drier portions of Swanland.

Karri and Jarrah have a world-wide reputation, and they are exported much more than any other Australian timber. They are greatly used for wood-blocks, piles, etc.

The following table shows concisely how man has adapted these belts to his needs.

Rainfall.	Timber.	Crop.	Towns and Mean Monthly Temperature.
Over 30 inches. Warmer moiety.	Tuart.	Dairies. Vines. Oranges. Sheep.	Perth (Jan. 74°, July 55°), Pinjarra.
Over 30 inches. Cooler moiety.	Jarrah. Karri.	Dairies. Apples. Sheep.	Bunbury, Denmark; Albany (Jan. 66°, July 53°).
30-20 inches.	Jarrah.	Vines. Farms.	Gingin. (Lately opened up in south.)
20-15 inches.	Wandoo. York Gum.	Great Wheat Belt.	Moora, Northam, York, Narrogin (Jan. 72°, July 50°).
15-12 inches.	York Gum.	Dry Wheat Belt. Sheep.	Kellerberrin (Jan. 77°, July 50°).
12-8 inches.	Mallet Gum. Gimlet ,, Salmon ,,	Few Sheep and Cattle.	Carnarvon (80°, 61°), Yalgoo, Southern Cross, Kalgoorlie (77°, 51°).

Wheat is by far the chief crop (78 per cent) and is progressing very rapidly in Swanland, for it has quadrupled its production from 1911 to

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1916. Some wheat is grown with as low an average rainfall as 12 inches per annum. (As mentioned elsewhere, these localities occasionally have *less than 10 inches* in one year, and yet may grow wheat fairly successfully with efficient fallowing.) There is little grown west of the 30-inch isohyet. The best areas seem to be those receiving from 15 to 20 inches in the cooler months (April to October). It must be remembered that this region is fortunate in having the most reliable rainfall in Australia. A great development of railways has taken place in the wheat belt of recent years, and this is perhaps the most favourable region of Australia for the immigrant.

As regards less important products, apples grow splendidly in the Karri region, while orchards are general in the Jarrah belt. The vine country lies between the wheat belt and the orchard belt.

§ 23. *Tasmania.*—Even more isolated from the economic centre of Australia than Swanland is the island State in the south-east. Tasmania lies 150 miles to the south of Victoria, between latitudes 40° and 44° S., and its climatic controls differ considerably from those of the mainland. It lies almost permanently under the influence of Antarctic low pressure systems, so that it is swept continuously by the Westerly winds blowing along their northern limbs. Hence the high western region of the island is too bleak and wet for settlement—a unique feature in arid Australia! A strip about 40 miles long, including Mt. Lyell, receives over 100 inches a year. The population is confined almost to the north and east, the chief economic centre being Launceston (January 64°, July 44°), though Hobart (January 62°, July 45°), in the south-east, is the capital. The tract from Wynyard to Launceston—with its excellent rainfall—is indeed one of the most populous in Tasmania. (See Fig. 9.)

FIG. 9.—The Rainfall Control of Vegetation and Crops in Tasmania.

In spite of Tasmania's small size (less than 1 per cent of the Commonwealth), in such crops as oats and potatoes it is close to Victoria, the leading State; while a much larger proportion of the population is engaged in orchards and hops than in any of the other States.

Oats are the chief crop, reaching two million bushels in 1916. The chief centres of production are along the north coast from Burnie to

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Longford, which receives from 40 to 50 inches of rain yearly. They are grown also in the eastern portion of the State, especially near Oatlands (20 to 30 inches).

Wheat is of much less importance and is apparently diminishing, for larger crops were obtained in 1860. Longford is perhaps the chief centre (20 to 30 inches).

The fruits grown in Tasmania include all those of temperate climes, but the two outstanding crops are apples and raspberries. The chief centre for both is in the south-east around Hobart. Potatoes are a very important crop on the wet north coast, especially the western half from Wynyard to Sheffield.

Timber is of considerable importance. Owing to the good rainfall the proportion of forest is greater than in any other State—for the whole except the western plateau is more or less covered. The trees are eucalypts (as elsewhere in Australia) in the east, but a different growth, due to the extremely heavy rainfall, obtains in the west and to the north-east in the Ben Lomond regions. Wherever the rain exceeds 50 inches yearly the eucalypt is largely replaced by the evergreen beech (*Fagus Cunninghami*), and this same tree is found in a similar habitat in the Victorian littoral. Moreover, on the west there are valuable areas of softwood pines.

BIBLIOGRAPHY.

The climatological aspects of Australian agriculture have hardly been discussed—apart from the few publications mentioned in the text—except in Government publications. A useful bibliography of works dealing with Australian resources is given in the *Commonwealth Year Book*. A more detailed physiographic list will be found in the writer's monograph "The Australian Environment." Each State publishes monthly an *Agricultural Gazette*, which is full of practical information and occasionally contains climatic articles.

The *Statistical Registers* for the several States are the sources of much of the preceding information as to distribution. They contain no maps, however, and hence it is not easy for readers outside Australia to make use of them. The *State Year Books* are better in this respect. I must record my great indebtedness to the *Commonwealth Year Book*, which is acknowledged generally to be a model of its kind. Readers are referred to the *Pastoral Review* (Melbourne), a private journal which gives excellent summaries of conditions month by month as well as lengthy articles on agricultural topics.

The study of the climatic control of production has been one of the writer's main duties during the last five years; so that the following list of books and memoirs may be helpful to English readers.

1916. "The climatic control of Australian production." Melbourne, Commonwealth Bureau of Meteorology. Bull. 11. 4°. Pp. 32, illus.

1916. "The control of settlement by humidity and temperature." Melbourne, Commonwealth Bureau of Meteorology. Bull. 14. 4°. Pp. 32, graphs 70.

1918. "The Australian environment." Melbourne, Federal Advisory Council, Science and Industry. Memoir 1. 4°. Pp. 188, maps.

1918. "Geographical factors controlling the settlement of tropical Australia." *Brisbane, Queensland Geog. J.*, **32-33**, 1916–18, pp. 1-67; reprinted *Geog. Review, New York, N. Y.*, **8**, 1919, pp. 84-115.

1918. "The climatic factors influencing settlement in Australia." *Melbourne, Commonwealth Year Book*, **11**, pp. 84-101, pls. 6.

1920. "Australia in its physiographic and economic aspects" (3rd ed.). Oxford (Univ. Press). 8°. Pp. 256, diags.

1920. "Australian meteorology, a text-book including sections on aviation and climatology." Oxford (Univ. Press). 8°. Pp. xi + 312.

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DISCUSSION.

Mr. J. S. DINES said that the Society was to be congratulated on having received this contribution from Dr. Griffith Taylor, who was well known for his works on Australian climatology. In this paper he had used his meteorology in a practical way by putting together the weather conditions in different parts of the country, and the crops and other produce which could be raised. It was a comprehensive work and would be very useful to intending settlers, telling them not only the different kinds of crops which can be grown but also the districts favourable to each. One point to be noticed was the honesty of the author. Colonial writers were sometimes tempted to paint the climate of their country in unduly rosy hues, but Dr. Taylor stated quite frankly that certain parts of Australia could never be of much value for crops or stock-raising, and for this reason when he referred to certain other parts which could be developed it carried the more weight.

Mr. C. E. P. BROOKS said that Australia in its configuration seemed to be happier than South Africa, where, owing to the considerable elevation of the interior, the rain ran rapidly off the surface into the rivers and then swiftly to the sea without doing much good to the soil. In Australia the interior was generally low, consequently the run-off was slower and the farmers could obtain crops on a smaller annual rainfall.

Mr. R. INWARDS asked whether the author had referred to the great deposits of water which were supposed to exist at great depths in the interior of Australia. Artesian wells were said to have been sunk, and a great amount of water found in quite rainless parts. He had heard it wildly suggested that the water percolated through from the high land in India.

Mr. W. W. BRYANT said that there seemed to be an extraordinary range of rainfall in Australia, yet Australians considered that they had a beautiful climate.

The PRESIDENT (Mr. R. H. HOOKER) said, in reply to Mr. Inwards, that the author referred to artesian wells generally but not specifically. They seemed to be generally on the western slope of the mountains, from which it would appear that they might be supplied from the rain falling on the mountains flowing westwards underground. A very cordial vote of thanks was passed to Dr. Taylor.

Mr. C. E. P. BROOKS writes with reference to Mr. Inwards' remarks about artesian wells, that it is interesting to recall Professor J. W. Gregory's remarkable theory in his book *The Dead Heart of Australia* (1906). According to this theory, the present geological structure of the country has not the necessary basin form sufficiently well developed for artesian wells, the possible catchment area being too small. The alternative is to suppose that the artesian water is not derived from recent rainfall, but is, so to speak, fossil, like the oil which rises in a similar way in the shafts pierced in oilfields, and may be derived from the rainfall of a former geological period.

RETIREMENT OF SIR NAPIER SHAW, F.R.S.

The announcement of the retirement of Sir Napier Shaw from the Directorship of the Meteorological Office was made known to the public in September. It is hoped to publish an account of Sir Napier's work during the years that he has been connected with the official meteorology of this country in the next issue of the *Quarterly Journal*.

Sir Napier has been closely connected with the Royal Meteorological Society for very many years, and at the Annual General Meeting on January 21st last completed his second year of office as President.

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THE COMPOSITION, IONISATION AND VISCOSITY OF THE ATMOSPHERE AT GREAT HEIGHTS.

By S. CHAPMAN, M.A., D.Sc., F.R.S., F.R.Met.Soc., and E. A. MILNE, B.A., Fellow of Trinity College, Cambridge.

[Received February 26—Read June 16, 1920.]

CONTENTS.—1. Introductory. 2. The lighter gases of the atmosphere. 3. General formulae and theoretical results. 4. Numerical data. 5. Numerical results. Tables of density, pressure and composition. 6. General description of the variation with height of the density, pressure and composition of the atmosphere. 7. Penetration of the atmosphere by α-particles. 8. Ionisation by β- and γ-radiation. 9. Atmospheric ozone. 10. The kinematical viscosity of the atmosphere. 11. The mean free path. 12. Summary.

INTRODUCTORY.

§ 1. THE subject of the nature of the outer layers of the earth's atmosphere has received considerable attention in recent years. Starting from the well-established fact of the existence, above a height of 10-15 k., of a region in which the temperature is approximately constant, several investigators have discussed the variation with height of the pressure, density and composition of the upper atmosphere, and the extent to which this atmosphere may be deemed to reach. The interest of these investigations has been increased by recent theories as to the origins of aurorae, magnetic storms and magnetic variations in general—phenomena which the theories referred to attribute in part to the atmospheric absorption of certain types of solar radiation. The layers of the atmosphere which appear to be of importance are those between heights of, say, 20 k. and 130 k.; accordingly, information as accurate as possible is required as to the state of the atmosphere in this range. It has seemed desirable, therefore, to undertake a recalculation of the density, pressure, composition and viscosity of the upper air at various heights, and to employ the results to estimate the penetrability of the atmosphere by extra-terrestrial radiation of the type producing ionisation. The assumptions on which the calculations are based are somewhat different from those previously made in similar calculations, and it will be necessary to examine in what way, if any, the conclusions obtained depend on the precise form of the assumptions made.

The portion of the atmosphere accessible to direct meteorological observations has been divided into two regions. The lower, called the troposphere, is distinguished by the existence of a temperature gradient; the temperature on the whole decreases from the ground upwards, the mean gradient being in the neighbourhood of 6° C. per k. The upper, called the stratosphere, is distinguished by the absence of any systematic temperature gradient; its temperature on any given occasion is on the whole constant, and, excluding its lowest layers, such small gradients as occur (amounting as a rule to not more than 1° C. per k.) may be either positive or negative. The boundary between the two regions is in general quite definite; usually there is a definite height at which the temperature gradient of the troposphere ceases, though sometimes the gradient may diminish more gradually; frequently the stratosphere

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commences with an inversion of the gradient which may persist through several degrees. The mean height of the boundary over England is between 10 and 11 k., though on different occasions and in different places it may vary from 10 k. to 15 k.

It is well recognised that the temperature gradient of the troposphere is intimately connected with the convective mixing which is continually taking place. Masses of air are continually being raised or lowered, and thus moved to places where the pressure is different; they expand or contract nearly adiabatically, and the consequent cooling or warming influences the temperature distribution. If the contents of the troposphere were always thoroughly mixed by mass motion, and if no heat exchanges took place by conduction or radiation, the temperature distribution would be that of an atmosphere in adiabatic equilibrium, *i.e.* a temperature distribution such that the adiabatic heating or cooling to which a mass of gas is subject when moved from one level to another automatically brings its temperature to that of its surroundings. In the troposphere the heat-exchanges due to radiation and conduction (particularly through eddies) reduce the gradient below that of adiabatic equilibrium, so that the gradient actually realised is little more than half the adiabatic gradient.

In the stratosphere, on the other hand, the absence of a temperature gradient seems incompatible with large-scale mixing, and it is generally supposed that there is no convective motion in the stratosphere. It is described as an atmosphere in isothermal equilibrium. There seems, however, little reason to suppose that the processes of convection necessarily cease suddenly at the boundary between the stratosphere and the troposphere. Convective mixing by itself would, of course, imply a temperature gradient, but the effect of a restricted amount of convective mixing could probably be neutralised by radiation. The frequent existence at the base of the stratosphere of a temperature gradient positive upwards shows that the processes operative in the stratosphere may be such as to communicate more heat to certain layers than to those below them, and hence it is possible that these processes might be able to maintain the temperature constant even when convective mixing is tending to produce a negative temperature gradient. In fact it has been shown by Gold[1] that at sufficiently great heights an adiabatic gradient could not be permanent, for the energy absorbed by the air would exceed that radiated, and so its temperature would be increasing. We may therefore conclude that a limited amount of convective mixing may take place near the base of the stratosphere. The winds in the upper air, which will act as mixing agents, fall off rapidly as the boundary between the troposphere and stratosphere is passed, and are quite small at about 18 to 20 k., at which height, it has been found, the pressure is practically the same everywhere. It is clear, therefore, that in comparison with the troposphere the large-scale mixing in the stratosphere is small; though we do not know precisely where it may be considered to cease, we may assume that at sufficiently great distances from the boundary the mixing is negligible. The various tables given later are worked out for the cases in which mixing effectively ceases at heights of 12 k., 20 k., 30 k., and 50 k. respectively.

[1] *London, Proc. R. Soc.*, **82** (ser. A), 1909, p. 43.

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Perhaps 20 k. is the best approximation to take for the effective height.

The extent to which mixing occurs is of importance in connection with the question of diffusion. The air consists of a mixture of gases in the presence of an external field of force, namely, that of gravity. The latter is a body force, *i.e.* the magnitude of the force acting on any body is proportional to the mass of that body. The kinetic theory of gases shows that under such circumstances, if the gas mixture is undisturbed, the heavier molecules will tend to move to the regions of the field in which the potential is least. Thus if the atmosphere were undisturbed, the constituents of large molecular weight would tend to diffuse to the bottom, whilst those of low molecular weight would tend to diffuse to the top, so that the proportion of any constituent to that of any heavier constituent would continually increase from the bottom upwards. The process of diffusion in gases is however comparatively slow, and in the troposphere it is completely counteracted by the large-scale mixing already referred to. Analysis of samples of air shows in fact that the composition of the troposphere is practically constant.[1] But in the stratosphere, or rather in those regions of it in which the convective mixing is negligible, there is nothing to oppose the tendency of the constituents to settle out according to their molecular weights. Accordingly it has to be supposed that above the level at which mixing ceases the composition of the atmosphere varies with the height. The mode of variation is that prescribed by Dalton's law, which states that the law of variation of density of each constituent is the same as if it alone was present.

Calculations of the composition of the atmosphere at various heights have been made by Hann,[2] Humphreys,[3] Wegener,[4] Jeans[5] and others. These calculations all illustrate a fact which it is important to emphasise, namely, that since the proportion of any light constituent to any heavy one continually increases with the height, therefore at sufficiently great heights the lightest constituent must form almost the whole of the atmosphere, however small its proportions in the lower regions. For the investigation of phenomena requiring a knowledge of the composition of the air at great heights, it is obviously highly important to ascertain the full constituents of the atmosphere of low molecular weight. It is almost more important to determine precisely what are these constituents than to determine their proportions. This question is considered in the next section. It may be pointed out here that the composition of the air at the base of the stratosphere will, owing to mixing, be almost the same as that throughout the troposphere and therefore almost the same as at the earth's surface.

[1] Save as to the content of water vapour. The argument only refers to gases at temperatures sufficiently removed from those at which they condense.

[2] *Meteor. Zs. Braunsweig*, **20**, 1903, p. 122.

[3] *Washington, D.C., U.S. Dept. Agric., Mount Weather Obs. Bull.*, **2** (2), 1910, p. 66.

[4] *Physic. Zs. Leipzig*, **12**, 1911, nos. 5, 6. "Thermodynamik der Atmosphäre," Leipzig, 1911, p. 46.

[5] *Washington, D.C., U.S. Dept. Agric., Mount Weather Obs. Bull.*, **2** (6), 1910, p. 347. "Dynamical Theory of Gases," 2 ed. Cambridge, 1916, p. 356.

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The Lighter Gases of the Atmosphere.

§ 2. The constituents of the atmosphere which are of molecular weight less than the mean "molecular weight of air" are given in the following list:

Gas.	Molecular Weight.	Gas.	Molecular Weight.
Nitrogen . . .	28	Ammonia . . .	17
Neon . . .	20	Helium . . .	4
Water vapour . .	18	Hydrogen . . .	2

In an examination of the rôles of these gases in the upper atmosphere, regard must be paid to the two following considerations:

A. *Direct evidence as to the presence of any particular gas in the stratosphere.*—Such evidence is obtained by the study of the spectra of aurorae and meteor trails. Aurorae occur almost entirely within the range 100 to 130 k., with maximum frequencies at 100 k. and 106 k. Auroral spectra consist principally of the spectrum of nitrogen together with a bright line in the green ($\lambda = 5570$) of unknown origin. The source of this line has been the subject of much speculation; it very nearly coincides with one of the principal krypton lines ($\lambda = 5570{\cdot}4$), but the other krypton line is absent, or at least is not present with the intensity to be expected if krypton were the source of the former one.[1] Neither hydrogen nor helium are known to appear in auroral spectra. As for the spectra of meteor trails, Dewar[2] refers to "Pickering's isolated observation of the spectrum of a meteor trail which seemed to consist chiefly of the spectra of hydrogen and helium," but gives no reference to the original record;[3] no other references to such spectra have been found. [Some information as to the *pressure* at great heights may be afforded by observations of the *duration* of luminosity of meteor trails.[4]]

B. *The possibility of the removal of gaseous constituents from the atmosphere.*

(*a*) *Escape from the outer fringe of the atmosphere.*—If a molecule of gas in the atmosphere became endowed, in the course of its collisions, with a velocity greater than that which would be acquired by a particle falling to the earth "from infinity" under the influence of gravitational attraction, and if this molecule happened to encounter no other molecules afterwards, then it would describe a hyperbolic orbit about the earth and be lost to the earth's atmosphere for ever. Now at great heights, the density becomes so small that the mean free path is very large and may amount to thousands of kilometres.[5] The actual chances of collision are then so small that some molecules may avoid collision altogether, and the small proportion of these which have exceptionally high velocities will then behave as independent satellites of the earth, and will fly off in the way just described. By taking account of the statistical distribution of velocities amongst the molecules of a gas, it is possible to calculate the proportion capable, at any moment, of escaping altogether from the atmosphere, and by effecting this calculation for a height at

[1] It would be difficult in any case to account for the presence of krypton in appreciable quantities at so great heights, owing to its large molecular weight (83).

[2] *London, Proc. R. Inst.*, **17**, 1902 (1903), p. 223.

[3] Presumably this has not been confirmed. According to Bohr's theory of spectra, the Balmer hydrogen series (for example) can also be emitted by helium.

[4] Jeans, J. H., *Washington, D.C., U.S. Dept. Agric., Mount Weather Obs. Bull.*, **2** (6), 1910, who quotes Trowbridge, *Observatory, London*, Nov. 1908.

[5] See Table XXIX. below.

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which the chances of collision are sufficiently small, it is possible to calculate the rate of loss of molecules from the atmosphere. Tables from which may be found the rate of loss of various atmospheric constituents are given by Jeans.[1] Since the mean energy possessed by different molecules is the same (for a given temperature), the lighter molecules have on the whole the greater velocities, and are therefore more likely to escape from the atmosphere. It appears, however, that for hydrogen and heavier gases the rate of loss from the earth's atmosphere is quite inappreciable, even when measured over periods of time astronomically large. The earth's atmosphere may therefore be deemed to be retaining hydrogen and *a fortiori* all heavier constituents. The critical velocity would, however, be reached in large proportions by the molecules of a gas which was of only half the molecular weight of hydrogen, so that no gas of molecular weight less than unity (should such exist) could be retained.

(*b*) *Possibilities of chemical combination.*—A constituent would tend to be removed from the atmosphere if opportunities occurred for it to combine with another constituent. Thus it is necessary to discuss the possibility of combination between the free hydrogen and free oxygen of the atmosphere. On the other hand, the constituents of the argon group must be permanent, and nitrogen too is so inert that it can be regarded as permanent.

We can now consider the light constituents enumerated above.

Nitrogen.—The tables given later show that nitrogen should be a prominent constituent up to nearly 200 k., and the auroral spectrum confirms its presence.

Neon.—This gas is present in the troposphere to the extent of 1 part in 80,000 by volume. The tables show that it should reach its maximum proportion at about 100 k. This proportion, however, is only 1 part in 2500 (roughly) by volume, which for most purposes is inappreciable. The rosy colour of some of the auroral manifestations has been attributed to neon.[2]

Water vapour.—Reliable determinations of the humidity of the atmosphere above the limits of the troposphere do not seem to have been made, but the relative humidity is always found to be small. Now at $-54°$ C. (the mean temperature of the stratosphere over England) the saturated vapour pressure of ice is about ·019 mm., or ·025 mb., and hence, the total pressure at the base of the stratosphere being roughly 200 mb., the proportion of water vapour here cannot exceed 1 part in 8000 by volume. From the figures quoted above for neon (the molecular weights of water and neon being nearly the same) it follows that the maximum proportion of water vapour cannot exceed 1 part in 250, and this maximum would occur at about 100 k. The actual proportions of water vapour will be much smaller than this, and in virtue of the uncertainty of the amount the water vapour will be omitted from the calculations.

Ammonia.—Traces of this gas have been found in the atmosphere in varying proportions, probably produced by organic decomposition on the ground. If present at all in the stratosphere it would reach its

[1] *Dyn. Theory of Gases*, p. 361. Also Bryan, *London, Phil. Trans. R. Soc.*, **196** (ser. A), p. 12.

[2] Dewar, *London, Proc. R. Inst.*, **17**, 1902 (1903), p. 223.

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maximum proportion in the neighbourhood of 100 k. Auroral spectra, however, provide no evidence for the presence of ammonia. Such ammonia as is generated near the ground must probably be washed down by rain (owing to its excessive solubility) before reaching the stratosphere. It will be neglected in the calculations.

Helium.—This gas, present in the atmosphere in the proportion of 1 part in 250,000 by volume, has perhaps been generated from the radioactive minerals. Being almost insoluble in water, and chemically inert, and being moreover easily retained by gravitational attraction, it must be a permanent constituent of the stratosphere, and owing to its low molecular weight (twice that of hydrogen) it must, at sufficiently great heights, be present in a proportion large compared with its proportion at the base of the stratosphere; for example, at 100 k. there should be nearly three times as much helium as oxygen, $\frac{1}{10}$ as much as nitrogen. It is therefore somewhat strange that helium should not be shown by the auroral spectrum. This must not, however, be taken as indicative of the absence of helium, for much will depend on the physical circumstances attending the appearance of aurorae, and as we have seen helium must be present in the stratosphere.

Hydrogen.—Great uncertainty attaches to the amount of free hydrogen in the atmosphere. If it is present at all at the base of the stratosphere, then at greater heights it will be present in very large proportions, for its molecular weight is small compared with those of all the other atmospheric constituents and it should be retained by gravitation. Indeed, at heights above 150 k., the atmosphere would consist almost entirely of hydrogen. Hydrogen, like helium, is not indicated by the auroral spectrum, though this alone does not prove its absence. However, it may reasonably be doubted whether there can be any free hydrogen at the base of the stratosphere. The proportion in the atmosphere at the earth's surface has been measured by various experimenters, who all agree that hydrogen is actually present, but whose numerical results are on the whole discordant. Gautier[1] determined the proportion as 2 parts in 10,000 by volume. His results were criticised by Lord Rayleigh[2] and Leduc,[3] both of whom adduced reasons for supposing that the amount of hydrogen was considerably less than that found by Gautier. Lord Rayleigh's own experiments, conducted on lines similar to Gautier's, determined the average hydrogen content as not more than $\frac{1}{7}$ of that found by Gautier, and he demonstrated, moreover, that his method accurately measured a known additional amount of hydrogen artificially introduced into the air used. Gautier replied to some of these criticisms later.[4] Dewar's[5] experiments on liquefaction indicated that the proportion was not more than 1 part in 100,000, whilst by a different fractional condensation method Claude[6] found the hydrogen content to be less than 1 part in 1,000,000.[7] Recently, by a volumetric contraction method, Krogh[8] found the total volume of combustible gases in the atmosphere to be certainly less

[1] *Ann. d. Chem.*, **22**, 1901, Jan.
[2] *Phil. Mag., London*, **3**, 1902, p. 416.
[3] *Paris, C.R. Acad. sci.*, **135**, p. 860.
[4] *Paris, C.R. Acad. sci.*, **135**, p. 1025.
[5] Dewar, *loc. cit.*
[6] *Paris, C.R. Acad. sci.*, **148** (1909), p. 1454.
[7] This summary is an amplification of one given by Wegener, *loc. cit.*, pp. 23-29.
[8] *Kjöbenhavn, Vid. Selsk. Skr., Mat.-fys. Medd.*, I. 12 (1919). (From Lab. of Zoophysiology, Copenhagen.)

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than 5 parts in 1,000,000 and probably less than 2 parts in 1,000,000. Lord Rayleigh's[1] determinations showed large individual variations, which suggests that the true hydrogen content may be variable, though Krogh's work and that of Benedict[2] has shown that as regards the principal constituents the composition is constant to 2 or 3 parts in 100,000. Any real variability would suggest that there may be processes tending to remove hydrogen from the atmosphere as well as processes tending to generate it. Hydrogen is evolved in organic decomposition near the ground, and discharged in company with other gases from volcanoes, etc.; but it may be expected to combine with oxygen through the action of lightning and possibly of sunlight. The process might be expedited by the presence of ozone, which is known to exist in the atmosphere;[3] the mixture known as electrolytic gas, which contains a small proportion of ozone, tends to unite and form water under the action of sunlight. Lastly, any hydrogen present in the auroral layer might tend to unite with oxygen through the action of auroral discharges.

Having then regard to:

(i.) the uncertainty in, and smallness of, the amount of free hydrogen in the atmosphere near the ground;

(ii.) the opportunities for this hydrogen to unite with oxygen before diffusing to the stratosphere, and the further opportunities in the stratosphere;

(iii.) the absence of any direct evidence of the existence of a hydrogen atmosphere at great heights,

it seems reasonable to take into consideration as a serious possibility the assumption that the stratosphere contains no free hydrogen. The case when hydrogen is present has been sufficiently discussed by Jeans, and accordingly for the purpose of the greater part of this paper the absence of hydrogen will be assumed. When for the sake of comparison it is required to estimate the effect of a hydrogen atmosphere, the proportion of hydrogen at the base of the stratosphere will be taken as 1 part in 100,000 by volume, or 7 parts in 10,000,000 by mass.

In the absence of hydrogen it will be seen later that above 100 k. helium should be present in appreciable proportion, and that above 120 to 130 k. it should be the predominant constituent; above 200 k. there should be practically an atmosphere of helium. This conclusion holds, of course, provided the atmosphere contains no other constituent of molecular weight less than that of helium. The hypothesis that there is such a constituent has been advanced by Wegener,[4] who thus accounts for the existence of the unknown bright line in the auroral spectrum. Wegener calls this constituent "geo-coronium," and identifies it with an inert, monatomic gas, of molecular weight 0·4, stated to be required by Mendelejeff's periodic table of the elements. Wegener gives reasons for supposing that this new constituent will have, on a rough estimate, a partial pressure which becomes equal to that of hydrogen at a height of 200 k. The proportion of this element can then be calculated for all heights, and it is found that geo-coronium should be present in the troposphere to the extent of ·00058 per cent (by volume).

[1] Rayleigh used samples of "country air."

[2] *Washington, D.C., Carnegie Inst., Publ.*, No. 166, 1912. (Quoted by Krogh.)

[3] See § 8 below.

[4] *Loc. cit.* (*Thermodyn. d. Atmosph.*, p. 27).

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Now the existence of atmospheric constituents of low molecular weight is very important in calculations of the pressure at various heights. The lighter the constituent the less it is concentrated in the lower layers, and thus the greater is its pressure at any height, for the pressure is the weight of overlying gas per unit area. Comparison of Wegener's table of pressure variations with those calculated on the assumption of the absence of geo-coronium will show how large an effect is exercised on the pressure by a mere trace of light gas existing in the troposphere. It would seem, then, to be a matter of some importance to decide for or against the existence or presence of geo-coronium. The uncertainty in the matter of hydrogen has already been discussed, but it appears to be much easier to decide against the presence of geo-coronium. It does not seem to have been pointed out that the earth's atmosphere could not retain geo-coronium, if its molecular weight is so low as 0·4. From the formulae given by Jeans it can be calculated that a constituent of molecular weight 0·4 would be entirely dissipated in a time comparable with one year. In fact Jeans' tables show that a constituent whose mean molecular velocity was $2{\cdot}9 \times 10^5$ cms. sec.$^{-1}$ would be dissipated in 1000 years, whilst it is easily found that at $-54°$ C. the mean molecular velocity of geo-coronium [1] would be $3{\cdot}7 \times 10^5$ cms. sec.$^{-1}$.

It thus appears that an atmosphere of geo-coronium could not be permanent, and that some other origin must be sought for the unknown line in the auroral spectrum.

General Formulae and Theoretical Results.

§ 3. It is convenient to obtain here the well-known formulae for the variation of pressure and density in an isothermal atmosphere, and to make simple deductions concerning the effect of an alteration in the height at which the separation of constituents by diffusion commences.

Let us denote by

H_0 the height of a suitable reference point near the base of the stratosphere at which the density and pressure are supposed known;

H_1 ($H_1 \geqslant H_0$) the effective height at which diffusion commences; below this height the composition is uniform; above, it is determined by Dalton's law;

Δ, Δ_1, Δ_0 the total density at any height z, at height H_1 and at height H_0, respectively;

ρ_s, ρ_s^1, ρ_s^0 the partial densities of a constituent at the same height (the suffix s identifies the constituent);

P, P_1, P_0 the total pressures;

v_s, p_s^1, p_s^0 the partial pressures of a constituent;

m_s the mass of a molecule of the s-constituent;

ν, ν_s the total number of molecules of air per unit volume, and the number per unit volume of the s-constituent, at height z;

$\bar{m}$ the "mean molecular weight" of air below height H_1;

α_s the proportion by mass of the s-constituent below height H_1;

T the absolute temperature of the stratosphere;

R the universal gas-constant;

a the mean radius of the earth.

[1] Only if the temperature fell to $-190°$ C. could it be retained.

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We have then immediately

$$\Sigma\nu_s = \nu, \quad \Sigma\alpha_s = 1, \quad \Sigma\rho_s = \Delta, \quad \Sigma p_s = \mathrm{P}, \quad . \quad . \quad . \quad (1)$$

$$\left.\begin{aligned} \rho_s &= \nu_s m_s, \\ p_s &= \nu_s \mathrm{R}\,\mathrm{T} = \frac{\mathrm{R}}{m_s}\rho_s \mathrm{T}. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Since the composition of the air is constant in the interval $(\mathrm{H}_0, \mathrm{H}_1)$, therefore for values of z in this interval

$$\left.\begin{aligned} \alpha_s &= \frac{\rho_s}{\Delta} = \frac{\nu_s m_s}{\Delta}, \\ \bar{m} &= \frac{\Sigma\nu_s m_s}{\Sigma\nu_s} = \frac{\Sigma\rho_s}{\nu} = \frac{\Delta}{\nu}, \\ \text{and} \qquad \bar{m} &= \frac{\Delta\Sigma\alpha_s}{\Delta\Sigma\frac{\alpha_s}{m_s}} = \frac{1}{\Sigma\frac{\alpha_s}{m_s}}. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

Lastly, in the interval $(\mathrm{H}_0, \mathrm{H}_1)$

$$\mathrm{P} = \Delta\mathrm{RT}\,\Sigma\frac{\alpha_s}{m_s} = \frac{\mathrm{R}}{\bar{m}}\Delta\mathrm{T}. \quad . \quad . \quad . \quad . \quad (4)$$

In the following we shall take into account the variation of gravity with height, but we shall ignore the rotation of the earth. The effect of this omission will be estimated later.

Variation of density and pressure in the interval (H_0, H_1).—The acceleration due to gravity at height z being $g\left(\frac{a}{a+z}\right)^2$, the equation expressing the statical equilibrium of the air column is

$$d\mathrm{P} = -g\left(\frac{a}{a+z}\right)^2 \Delta dz,$$

which by (4) gives

$$\frac{d\mathrm{P}}{\mathrm{P}} = \frac{d\Delta}{\Delta} = -\frac{g\bar{m}}{\mathrm{RT}}\left(\frac{a}{a+z}\right)^2 dz.$$

Integrating, we find

$$log\,\frac{\mathrm{P}}{\mathrm{P}_0} = log\,\frac{\Delta}{\Delta_0} = -\frac{gma^2}{\mathrm{RT}}\left\{\frac{1}{a+\mathrm{H}_0} - \frac{1}{a+z}\right\}.$$

In particular,

$$log\,\frac{\mathrm{P}_1}{\mathrm{P}_0} = log\,\frac{\Delta_1}{\Delta_0} = -\frac{g\bar{m}a^2}{\mathrm{RT}}\left\{\frac{1}{a+\mathrm{H}_0} - \frac{1}{a+\mathrm{H}_1}\right\}. \quad . \quad . \quad . \quad (5)$$

Variation of density and pressure in the region above height H_1.—Here the constituents separate out by diffusion, and we consider each constituent separately. We have then

$$dp_s = -g\left(\frac{a}{a+z}\right)^2 \rho_s dz,$$

which by (2) gives

$$\frac{dp_s}{p_s} = \frac{d\rho_s}{\rho_s} = -\frac{gm_s}{\mathrm{RT}}\left(\frac{a}{a+z}\right)^2 dz.$$

Integrating, we find

$$log\,\frac{p_s}{p_s^1} = log\,\frac{\rho_s}{\rho_s^1} = -\frac{gm_s a^2}{\mathrm{RT}}\left(\frac{1}{a+\mathrm{H}_1} - \frac{1}{a+z}\right) \quad . \quad . \quad . \quad (6)$$

in which $\qquad p_s^1 = \frac{\alpha_s \mathrm{P}_1 \bar{m}}{m_s}, \quad \rho_s^1 = \alpha_s \Delta_1.$

The total density is given by

$$\Delta = \Sigma\rho_s, \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and the total pressure by

$$\mathrm{P} = \Sigma p_s = \Sigma\frac{\mathrm{RT}}{m_s}\rho_s. \quad . \quad . \quad . \quad . \quad (8)$$

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From (6) we can see immediately that the proportion of any heavy constituent to any light one steadily decreases as z increases; for if the suffixes 1 and 2 are used to denote two assigned constituents, we have

$$\frac{\rho_1}{\rho_2} = \frac{\alpha_1}{\alpha_2} e^{-\frac{g a^2}{RT}\frac{z-H_1}{(a+H_1)(a+z)}(m_1-m_2)}, \quad . \quad . \quad . \quad (9)$$

and if $m_1 > m_2$ the ratio ρ_1/ρ_2 steadily decreases as z increases.

Effect of a variation of H_1.—We consider in detail the effect of a change in H_1 on the partial and total densities and pressures, and on the composition.

(1) *Variation of pressure and density of any constituent.*—Combining (5) and (6) we find

$$\frac{m_s}{\bar{m}}\frac{p_s}{p_0} = \frac{\rho_s}{\Delta_0} = \alpha_s e^{-\frac{g\bar{m}a^2}{RT}\left(\frac{1}{a+H_0}-\frac{1}{a+H_1}\right)-\frac{gm_s a^2}{RT}\left(\frac{1}{a+H_1}-\frac{1}{a+z}\right)}. \quad . \quad (10)$$

$$\propto e^{-\frac{g}{RT}\frac{a^2}{a+H_1}(m_s-\bar{m})}.$$

Thus the pressure and density of any constituent at a given height z increase as H_1 increases if $m_s > \bar{m}$, and decrease as H_1 increases if $m_s < \bar{m}$. Hence the pressure and density of oxygen and all heavier constituents increase as H_1 increases, whilst those of nitrogen and all lighter constituents decrease.

(2) *Variation of the relative proportions of any two constituents.*—Using the suffixes 1 and 2 to denote the constituents, we have

$$\frac{\rho_1}{\rho_2} = \frac{\alpha_1}{\alpha_2} e^{-\frac{g a^2}{RT}\frac{m_1-m_2}{a+H_1}}.$$

Thus the proportion of any constituent to any lighter constituent increases (for a given height z) as H_1 increases. In other words, the smaller is H_1, the more complete is the degree of separation at any given height, or the more rapidly the separation occurs as the height increases.

(3) *Variation of total density.*—Differentiating (10) partially with regard to H_1, we find

$$\frac{1}{\rho_s}\frac{\partial \rho_s}{\partial H_1} = \frac{g}{RT}\left(\frac{a}{a+H_1}\right)^2 (m_s - \bar{m}),$$

whence

$$\frac{\partial \Delta}{\partial H_1} = \Sigma \frac{\partial \rho_s}{\partial H_1} = \frac{g}{RT}\left(\frac{a}{a+H_1}\right)^2 (\Sigma m_s \rho_s - \bar{m}\Sigma\rho_s)$$

or

$$\frac{1}{\Delta}\frac{\partial \Delta}{\partial H_1} = \frac{g}{RT}\left(\frac{a}{a+H_1}\right)^2 \left(\Sigma m_s \frac{\rho_s}{\Delta} - \bar{m}\right).$$

The sign of $\Sigma m_s \frac{\rho_s}{\Delta} - \bar{m}$ must now be discussed. For points only slightly above the height at which diffusion commences, ρ_s/Δ will be very nearly equal to α_s. Consider then the sign of $\Sigma \alpha_s m_s - \bar{m}$. Remembering that

$$\frac{1}{\bar{m}} = \Sigma \frac{\alpha_s}{m_s}, \quad \Sigma \alpha_s = 1,$$

we see that the sign is the same as that of

$$(\Sigma \alpha_s m_s)\left(\Sigma \frac{\alpha_s}{m_s}\right) - (\Sigma \alpha_s)^2,$$

i.e. of

$$\sum_{r,s} \alpha_r \alpha_s \left(\frac{m_r}{m_s} + \frac{m_s}{m_r} - 2\right),$$

which is essentially positive. Thus at points only slightly above the height at which separation commences the total density increases as H_1

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increases. On the other hand, for large value of z $\frac{\partial\Delta}{\partial H_1}$ must be negative; for $\Sigma m_s\rho_s/\Delta$ becomes practically equal to the molecular weight of the lightest constituent, which is of course less than $\bar{m}$. Hence for large values of z the total density decreases as H_1 increases. For the actual atmosphere, the height at which $\frac{\partial\Delta}{\partial H_1}$ vanishes[1] is practically fixed by the proportions of oxygen and nitrogen, and a simple calculation shows that this occurs about 6 k. above the height H_1.

(4) *Variation of total pressure.*—We have

$$P = \Sigma p_s = RT\Sigma\frac{\rho_s}{m_s},$$

so that
$$\frac{\delta P}{\delta H_1} = RT\Sigma\frac{1}{m_s}\cdot\frac{\delta\rho_s}{\delta H_1} = g\left(\frac{a}{a+H_1}\right)^2\Sigma\frac{\rho_s(m_s-\bar{m})}{m_s}.$$

This is essentially negative. For

$$\rho_s \propto a_s e^{-\kappa\lambda_s}$$

where κ is the same for the different constituents, and λ_s is written for $m_s - \bar{m}$, so that

$$\frac{\delta P}{\delta H_1} \propto \Sigma\frac{a_s\lambda_s}{m_s}e^{-\kappa\lambda_s}.$$

Now since
$$\frac{1}{\bar{m}} = \Sigma\frac{a_s}{m_s},$$

it follows that
$$\Sigma\frac{a_s\lambda_s}{m_s} = 0,$$

and therefore $\Sigma\frac{a_s\lambda_s}{m_s}e^{-\kappa\lambda_s}$ is negative, for κ is positive. Thus the pressure at any given height steadily decreases as H_1 increases.

Effect of change of temperature.—We wish to consider the effect of assuming a different temperature for the stratosphere. Suppose for definiteness that the pressure at height H_0 is unaltered, but that the whole stratosphere has now a temperature T′ less than T. As compared with the previous case the whole air will have sunk; the total mass above any given height will be reduced, and so the pressure will have decreased. At points near H_0 the density will have increased, but higher up it will have decreased, for at sufficiently great heights the reduction of pressure will more than counterbalance the decrease of temperature.

Put $T - T' = \delta T$ and let $\delta\rho_s$ denote the increase in ρ_s. Then approximately, when $z > H_1$,

$$\frac{\delta\rho_s}{\rho_s} = \frac{\delta T}{T}\left[1 - \frac{\bar{m}gq^2}{RT}\left\{\frac{1}{a+H_0} - \frac{1}{a+H_1}\right\} - \frac{m_sgq^2}{RT}\left\{\frac{1}{a+H_1} - \frac{1}{a+z}\right\}\right].$$

(If $z < H_1$, the value of $\delta\rho$ is obtained by replacing H_1 by z). Substituting the numerical value of $\bar{m}g/RT$ and neglecting the differences between a, $a + H_1$, etc., this becomes

$$\frac{\delta\rho_s}{\rho_s} = \frac{\delta T}{T}\left[1 - 0{\cdot}126\ (q + \frac{m_s}{\bar{m}}q')\right],$$

where q, q' denote respectively the number of kilometres in $H_1 - H_0$,

[1] It is easily shown that $\frac{1}{\Delta}\frac{\partial\Delta}{\partial H_1}$ steadily decreases as z increases, so that $\frac{\partial\Delta}{\partial H_1}$ has only one zero.

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$z - H_1$. It appears that $\delta\rho_s$ is zero about 8 k. above the height H_0 above which the change of temperature occurs. The proportional change in ρ_s may, at great heights, become many times the proportional change in T. For example, for nitrogen at 100 k. height, we find

$$\frac{\delta\rho}{\rho} = -10\frac{\delta T}{T},$$

approximately; and for helium at 200 k. height (assuming $H_1 - H_0 = 10$ k.) we find

$$\frac{\delta\rho}{\rho} = -3{\cdot}4\frac{\delta T}{T}.$$

It is to be noted from equation (9) that the proportion of any constituent to any lighter constituent decreases as the temperature decreases, so that the colder the stratosphere the more rapid is the separation. Similarly, if the stratosphere is not wholly at a uniform temperature, the degree of separation increases with height more rapidly in the colder parts.

Neglect of earth's rotation.—For simplicity we will consider only points in the equatorial plane of the earth. If ω is the earth's angular velocity, the equation of statical equilibrium must be replaced by

$$dp_s + g\left(\frac{a}{a+z}\right)^2 \rho_s dz = \omega^2(a+z)\rho_s dz$$

or

$$\frac{1}{\rho_s}\frac{d\rho_s}{dz} = \frac{m_s}{RT}\left[\omega^2(a+z) - \frac{ga^2}{(a+z)^2}\right]$$

or

$$\log\frac{\rho_s}{\rho_s^1} = \frac{m_s}{RT}\left[\tfrac{1}{2}\omega^2\{(a+z)^2 - (a+H_1)^2\} + ga^2\left\{\frac{1}{a+z} - \frac{1}{a+H_1}\right\}\right].$$

Let $\delta\rho_s$ be the error introduced into ρ_s by neglecting rotation. Then (neglecting the very small error in ρ_s^1) we have

$$\frac{\delta\rho_s}{\rho_s} = \tfrac{1}{2}\frac{m_s\omega^2}{RT}(z - H_1)(2a + z + H_1),$$

or, substituting

$$\omega^2 a/g = 1/288,$$

$$\frac{\delta\rho_s}{\rho_s} = \frac{1}{288}\frac{gm_s}{RT}(z - H_1)$$

approximately. As an example, m_s/R for helium is $4{\cdot}8 \times 10^{-8}$, and when $z - H_1 = 200$ kms. $= 2 \times 10^7$ cms. we have

$$\frac{\delta\rho_s}{\rho_s} = \frac{4{\cdot}8 \times 981 \times 0{\cdot}2}{288 \times 219} = 0{\cdot}015,$$

and so the error in the density at 200 k. is $1\frac{1}{2}$ per cent. Though m_s is greater for the heavier constituents, it is not necessary to consider such large values of z; thus for nitrogen (whose density is seven times that of helium) the density is inappreciable beyond 150 k.

For simplicity in the calculations these errors will be neglected.

Numerical Data.

§ 4. *The composition of the atmosphere near the ground.*—The following figures for the composition of the atmosphere are taken from Kaye and Laby's *Physical and Chemical Constants*, the figures for the rare gases being due to Ramsay [1] and Claude.[2] Molecular weights, etc., are added.

[1] *London, Proc. R. Soc.*, **80**, 1908, p. 599.
[2] *Paris, C.R. Acad. sci.*, **148**, 1909, p. 1454.

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TABLE I.—Percentage Composition of the Atmosphere, excluding Water Vapour.

Gases.	Percentage Composition.		Relative Molecular Weight.	R/m.	m/R.
	By weight.	By volume.			
Nitrogen . .	75·5	78·05	28·02	$2{\cdot}966 \times 10^{8}$	$3{\cdot}371 \times 10^{-7}$
Oxygen . . .	23·2	21·0	32·00	2·596 ,,	3·852 ,,
Argon . . .	1·3	0·95	39·88	2·082 ,,	4·803 ,,
Carbon dioxide .	·046 to ·04	·03 to ·3	44·00	1·889 ,,	5·294 ,,
Krypton . . .	·028	·0097	82·92	1·001 ,,	$0{\cdot}999 \times 10^{-6}$
Xenon . . .	·005	·0011	130·2	$6{\cdot}34 \times 10^{6}$	1·58 ,,
Neon . . .	·00086	·00123	20·2	$4{\cdot}12 \times 10^{8}$	$2{\cdot}427 \times 10^{-7}$
Helium . . .	·000056	·00040	4·00	$2{\cdot}082 \times 10^{7}$	$4{\cdot}803 \times 10^{-8}$
(Air) . . .	...	...	(28·95)	$(2{\cdot}87 \times 10^{8})$	$(3{\cdot}485 \times 10^{-7})$

There are also present in the air traces of ozone, which will be referred to later. In the tables of densities, etc., given below, the carbon dioxide is ignored; it is convenient to do this, owing to its variable proportion, but in any case its high molecular weight (greater than that of argon, *q.v.*) will ensure its settling out in such a way that its proportion rapidly becomes negligible. A rough upper limit to the amount of carbon dioxide in any layer can be obtained by taking a quarter of the weight of argon in that layer.

Meteorological data.—The following table[1] gives the mean temperatures, pressures and densities as determined by meteorological observations for various heights over S.E. England.

TABLE II.—Mean Values for S.E. England.

Height in kilometres.	Temperature (abs. °C.).	Pressure (millibars).	Density (grammes per c.c.).
0	282	1014	$12{\cdot}50 \times 10^{-4}$
⋮	⋮	⋮	⋮
9	228	303	4·63 ,,
10	222	261	4·09 ,,
11	220	224	3·55 ,,
12	219	192	3·05 ,,
13	219	164	2·61 ,,
14	219	140	2·23 ,,
15	219	120	1·91 ,,
16	219	102	1·62 ,,
17	219	88	1·39 ,,
18	219	75	1·19 ,,
19	219	64	1·02 ,,
20	219	55	0·87 ,,

The mean values for Europe are substantially the same as these. The mean temperature of the stratosphere over Canada is some five or six degrees lower than that over Europe, whilst that over the equatorial

[1] Dines, "Characteristics of the Free Atmosphere" (London, Meteor. Off., *Geophysical Memoirs*, No. 13, p. 63).

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regions seems to be twenty or twenty-five degrees lower, though the figures are somewhat uncertain.

The following values will be adopted in calculations :—

$H_0 = 12$ k. $= 12 \times 10^5$ cms.
$T = 219°$ a. ($-54°$ C.).
$\triangle_0 = 3{\cdot}05 \times 10^{-4}$ grammes per c.c.
$P_0 = 192$ mb. $= 1{\cdot}92 \times 10^5$ dynes per sq. cm.
$g = 981{\cdot}2$ cms. sec.$^{-2}$.
$a = 6370$ kms. $= 6{\cdot}37 \times 10^8$ cms.

From these data the following table has been calculated. It gives the total density $\triangle_1$, and the partial densities ρ_s^1 at the height H_1 (beneath which there is no diffusive separation), for $H_1 = 12$, 20, 30, 50 k.

TABLE III.—Total Density (Δ_1) and Partial Densities (ρ_s^1) for various Values of H_1. (Densities in Grammes per c.c.)

H_1	12	20	30	50
Air (Δ_1).	$3{\cdot}05 \times 10^{-4}$	$8{\cdot}79 \times 10^{-5}$	$1{\cdot}867 \times 10^{-5}$	$8{\cdot}48 \times 10^{-7}$
Nitrogen . .	$2{\cdot}30 \times 10^{-4}$	$6{\cdot}64 \times 10^{-5}$	$1{\cdot}41 \times 10^{-5}$	$6{\cdot}40 \times 10^{-7}$
Oxygen . . .	$7{\cdot}08 \times 10^{-5}$	$2{\cdot}04 \times 10^{-5}$	$4{\cdot}33 \times 10^{-6}$	$1{\cdot}97 \times 10^{-7}$
Argon . . .	$3{\cdot}97 \times 10^{-6}$	$1{\cdot}14 \times 10^{-6}$	$2{\cdot}43 \times 10^{-7}$	$1{\cdot}10 \times 10^{-8}$
Krypton . . .	$8{\cdot}54 \times 10^{-8}$	$2{\cdot}46 \times 10^{-8}$	$5{\cdot}23 \times 10^{-9}$	$2{\cdot}37 \times 10^{-10}$
Xenon . . .	$1{\cdot}52 \times 10^{-8}$	$4{\cdot}4 \times 10^{-9}$	$9{\cdot}4 \times 10^{-10}$	$4{\cdot}2 \times 10^{-11}$
Neon . . .	$2{\cdot}62 \times 10^{-9}$	$7{\cdot}57 \times 10^{-10}$	$1{\cdot}61 \times 10^{-10}$	$7{\cdot}29 \times 10^{-12}$
Helium . . .	$1{\cdot}71 \times 10^{-10}$	$4{\cdot}92 \times 10^{-11}$	$1{\cdot}05 \times 10^{-11}$	$4{\cdot}74 \times 10^{-13}$
(Hydrogen)[1] . .	$2{\cdot}13 \times 10^{-10}$	$6{\cdot}16 \times 10^{-11}$	$1{\cdot}30 \times 10^{-11}$	$5{\cdot}94 \times 10^{-13}$

[1] The proportion assumed (p. 17) is 7×10^{-5} per cent by mass.

It is convenient to adduce here the following table of factors. The first column of figures gives the factor by which to multiply the partial density in order to arrive at the number of molecules per c.c. (assuming that the number of molecules in 1 c.c. of gas at 0° C. and 760 mm. pressure is $2{\cdot}75 \times 10^{19}$). The second column gives the factor by which to multiply the partial density in order to obtain the partial pressure (in dynes per sq. cm.) at a temperature of 219° a.

TABLE IV.

Air	$2{\cdot}13 \times 10^{22}$	$6{\cdot}28 \times 10^8$
Nitrogen	$2{\cdot}20 \times 10^{22}$	$6{\cdot}50 \times 10^8$
Oxygen	$1{\cdot}92$,,	$5{\cdot}68$,,
Argon	$1{\cdot}54$,,	$4{\cdot}56$,,
Krypton	$0{\cdot}742$,,	$2{\cdot}19$,,
Xenon	$0{\cdot}470$,,	$1{\cdot}39$,,
Neon	$3{\cdot}05$,,	$9{\cdot}02$,,
Helium	$15{\cdot}4$,,	$45{\cdot}6$,,
Hydrogen	$30{\cdot}6$,,	$90{\cdot}5$,,

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TABLE V.—Partial Densities of Atmospheric Constituents, in Grammes per c.c., for the case in which the Composition is determined by Diffusion above a Height of 12 k. ($H_1 = 12$ k.)

The column headed "Total" gives the total density, assuming hydrogen to be absent. The partial densities for hydrogen are given in the last column for comparison.

Height in kilometres.	Helium.	Neon.	Nitrogen.	Oxygen.	Argon.	Krypton.	Xenon.	Total.	(Hydrogen.)
12	$1{\cdot}71 \times 10^{-10}$	$2{\cdot}62 \times 10^{-9}$	$2{\cdot}303 \times 10^{-4}$	$7{\cdot}08 \times 10^{-5}$	$3{\cdot}96 \times 10^{-6}$	$8{\cdot}54 \times 10^{-8}$	$1{\cdot}52 \times 10^{-8}$	$3{\cdot}05 \times 10^{-4}$	$2{\cdot}13 \times 10^{-10}$
20	$1{\cdot}44 \times 10^{-10}$	$1{\cdot}10 \times 10^{-9}$	$6{\cdot}91 \times 10^{-5}$	$1{\cdot}79 \times 10^{-5}$	$7{\cdot}14 \times 10^{-7}$	$2{\cdot}48 \times 10^{-9}$	$5{\cdot}49 \times 10^{-11}$	$8{\cdot}77 \times 10^{-5}$	$1{\cdot}95 \times 10^{-10}$
40	$9{\cdot}39 \times 10^{-11}$	$1{\cdot}27 \times 10^{-10}$	$3{\cdot}46 \times 10^{-6}$	$5{\cdot}84 \times 10^{-7}$	$1{\cdot}00 \times 10^{-8}$	$3{\cdot}37 \times 10^{-13}$	$4{\cdot}59 \times 10^{-17}$	$4{\cdot}05 \times 10^{-6}$	$1{\cdot}58 \times 10^{-10}$
60	$6{\cdot}15 \times 10^{-11}$	$1{\cdot}50 \times 10^{-11}$	$1{\cdot}764 \times 10^{-7}$	$1{\cdot}95 \times 10^{-8}$	$1{\cdot}44 \times 10^{-10}$	$5{\cdot}00 \times 10^{-17}$	$4{\cdot}18 \times 10^{-23}$	$1{\cdot}96 \times 10^{-7}$	$1{\cdot}27 \times 10^{-10}$
80	$4{\cdot}03 \times 10^{-11}$	$1{\cdot}79 \times 10^{-12}$	$9{\cdot}17 \times 10^{-9}$	$6{\cdot}65 \times 10^{-10}$	$2{\cdot}14 \times 10^{-12}$	$7{\cdot}8 \times 10^{-21}$	...	$9{\cdot}88 \times 10^{-9}$	$1{\cdot}03 \times 10^{-10}$
100	$2{\cdot}65 \times 10^{-11}$	$2{\cdot}15 \times 10^{-13}$	$4{\cdot}84 \times 10^{-10}$	$2{\cdot}31 \times 10^{-11}$	$3{\cdot}24 \times 10^{-14}$	$1{\cdot}26 \times 10^{-24}$	...	$5{\cdot}34 \times 10^{-10}$	$8{\cdot}32 \times 10^{-11}$
106	$2{\cdot}34 \times 10^{-11}$	$1{\cdot}14 \times 10^{-13}$	$2{\cdot}015 \times 10^{-10}$	$8{\cdot}47 \times 10^{-12}$	$9{\cdot}29 \times 10^{-15}$	...	...	$2{\cdot}34 \times 10^{-10}$	$7{\cdot}82 \times 10^{-11}$
110	$2{\cdot}15 \times 10^{-11}$	$7{\cdot}51 \times 10^{-14}$	$1{\cdot}149 \times 10^{-10}$	$4{\cdot}36 \times 10^{-12}$	$4{\cdot}06 \times 10^{-15}$	...	...	$1{\cdot}41 \times 10^{-10}$	$7{\cdot}50 \times 10^{-11}$
120	$1{\cdot}75 \times 10^{-11}$	$2{\cdot}63 \times 10^{-14}$	$2{\cdot}621 \times 10^{-11}$	$8{\cdot}21 \times 10^{-13}$	$5{\cdot}06 \times 10^{-16}$	...	...	$4{\cdot}45 \times 10^{-11}$	$6{\cdot}75 \times 10^{-11}$
130	$1{\cdot}42 \times 10^{-11}$	$9{\cdot}23 \times 10^{-15}$	$6{\cdot}13 \times 10^{-12}$	$1{\cdot}56 \times 10^{-13}$	$6{\cdot}39 \times 10^{-17}$	...	...	$2{\cdot}05 \times 10^{-11}$	$6{\cdot}08 \times 10^{-11}$
140	$1{\cdot}16 \times 10^{-11}$	$3{\cdot}27 \times 10^{-15}$	$1{\cdot}446 \times 10^{-12}$	$3{\cdot}01 \times 10^{-14}$	$8{\cdot}09 \times 10^{-18}$	...	...	$1{\cdot}31 \times 10^{-11}$	$5{\cdot}49 \times 10^{-11}$
150	$9{\cdot}42 \times 10^{-12}$	$1{\cdot}15 \times 10^{-15}$	$3{\cdot}39 \times 10^{-13}$	$5{\cdot}59 \times 10^{-15}$	$1{\cdot}04 \times 10^{-18}$	...	...	$9{\cdot}76 \times 10^{-12}$	$4{\cdot}93 \times 10^{-11}$
200	$3{\cdot}40 \times 10^{-12}$	$6{\cdot}66 \times 10^{-18}$	$2{\cdot}65 \times 10^{-16}$	$1{\cdot}62 \times 10^{-18}$	$3{\cdot}87 \times 10^{-28}$	...	...	$3{\cdot}40 \times 10^{-12}$	$2{\cdot}95 \times 10^{-11}$
300	$4{\cdot}46 \times 10^{-13}$	$2{\cdot}81 \times 10^{-22}$	$2{\cdot}19 \times 10^{-22}$	$1{\cdot}82 \times 10^{-25}$	...	...	...	$4{\cdot}46 \times 10^{-13}$	$1{\cdot}08 \times 10^{-11}$
400	$6{\cdot}69 \times 10^{-14}$	...	...	...	...	...	...	$6{\cdot}69 \times 10^{-14}$	$4{\cdot}06 \times 10^{-12}$
600	$1{\cdot}65 \times 10^{-15}$	...	...	...	...	...	...	$1{\cdot}65 \times 10^{-15}$	$6{\cdot}28 \times 10^{-13}$
800	$4{\cdot}95 \times 10^{-17}$	...	...	...	...	...	...	$4{\cdot}95 \times 10^{-17}$	$1{\cdot}07 \times 10^{-13}$
1000	$1{\cdot}82 \times 10^{-18}$	...	...	...	...	...	...	$1{\cdot}82 \times 10^{-18}$	$2{\cdot}02 \times 10^{-14}$

TABLE VI.—Partial Densities of Atmospheric Constituents, in Grammes per c.c., for the case $H_1 = 20$ k.

Height in kilometres.	Helium.	Neon.	Nitrogen.	Oxygen.	Argon.	Krypton.	Xenon.	Total.	(Hydrogen.)
20	$4{\cdot}92 \times 10^{-11}$	$7{\cdot}57 \times 10^{-10}$	$6{\cdot}64 \times 10^{-5}$	$2{\cdot}04 \times 10^{-5}$	$1{\cdot}14 \times 10^{-6}$	$2{\cdot}46 \times 10^{-8}$	$4{\cdot}40 \times 10^{-9}$	$8{\cdot}79 \times 10^{-5}$	$6{\cdot}16 \times 10^{-11}$
40	$3{\cdot}22 \times 10^{-11}$	$8{\cdot}78 \times 10^{-11}$	$3{\cdot}33 \times 10^{-6}$	$6{\cdot}69 \times 10^{-7}$	$1{\cdot}61 \times 10^{-8}$	$3{\cdot}48 \times 10^{-12}$	$3{\cdot}74 \times 10^{-15}$	$4{\cdot}02 \times 10^{-6}$	$4{\cdot}97 \times 10^{-11}$
60	$2{\cdot}10 \times 10^{-11}$	$1{\cdot}03 \times 10^{-11}$	$1{\cdot}71 \times 10^{-7}$	$2{\cdot}24 \times 10^{-8}$	$2{\cdot}33 \times 10^{-10}$	$5{\cdot}23 \times 10^{-16}$	$3{\cdot}47 \times 10^{-21}$	$1{\cdot}93 \times 10^{-7}$	$4{\cdot}01 \times 10^{-11}$
80	$1{\cdot}38 \times 10^{-11}$	$1{\cdot}23 \times 10^{-12}$	$8{\cdot}90 \times 10^{-9}$	$7{\cdot}66 \times 10^{-10}$	$3{\cdot}47 \times 10^{-12}$	$8{\cdot}15 \times 10^{-20}$	$3{\cdot}47 \times 10^{-27}$	$9{\cdot}68 \times 10^{-9}$	$3{\cdot}14 \times 10^{-11}$
100	$9{\cdot}10 \times 10^{-12}$	$1{\cdot}49 \times 10^{-13}$	$4{\cdot}72 \times 10^{-10}$	$2{\cdot}68 \times 10^{-11}$	$5{\cdot}30 \times 10^{-14}$	$1{\cdot}38 \times 10^{-23}$	...	$5{\cdot}08 \times 10^{-10}$	$2{\cdot}63 \times 10^{-11}$
106	$7{\cdot}94 \times 10^{-13}$	$1{\cdot}20 \times 10^{-13}$	$1{\cdot}964 \times 10^{-10}$	$9{\cdot}83 \times 10^{-12}$	$1{\cdot}52 \times 10^{-14}$	...	...	$2{\cdot}14 \times 10^{-10}$	$2{\cdot}47 \times 10^{-11}$
110	$7{\cdot}39 \times 10^{-13}$	$5{\cdot}21 \times 10^{-14}$	$1{\cdot}097 \times 10^{-10}$	$5{\cdot}06 \times 10^{-12}$	$6{\cdot}62 \times 10^{-15}$	...	...	$1{\cdot}22 \times 10^{-10}$	$2{\cdot}37 \times 10^{-11}$
120	$6{\cdot}00 \times 10^{-13}$	$1{\cdot}82 \times 10^{-14}$	$2{\cdot}55 \times 10^{-11}$	$9{\cdot}55 \times 10^{-13}$	$8{\cdot}27 \times 10^{-16}$	...	...	$3{\cdot}25 \times 10^{-11}$	$2{\cdot}13 \times 10^{-11}$
130	$4{\cdot}88 \times 10^{-13}$	$6{\cdot}17 \times 10^{-15}$	$5{\cdot}98 \times 10^{-12}$	$1{\cdot}81 \times 10^{-13}$	$1{\cdot}04 \times 10^{-16}$	...	...	$1{\cdot}10 \times 10^{-11}$	$1{\cdot}92 \times 10^{-11}$
140	$3{\cdot}97 \times 10^{-13}$	$2{\cdot}26 \times 10^{-15}$	$1{\cdot}408 \times 10^{-12}$	$3{\cdot}48 \times 10^{-14}$	$1{\cdot}34 \times 10^{-17}$	...	...	$5{\cdot}41 \times 10^{-12}$	$1{\cdot}73 \times 10^{-11}$
150	$3{\cdot}23 \times 10^{-13}$	$8{\cdot}01 \times 10^{-16}$	$3{\cdot}33 \times 10^{-13}$	$6{\cdot}71 \times 10^{-15}$	$1{\cdot}69 \times 10^{-18}$	...	...	$3{\cdot}57 \times 10^{-12}$	$1{\cdot}56 \times 10^{-11}$
200	$1{\cdot}17 \times 10^{-13}$	$4{\cdot}66 \times 10^{-18}$	$2{\cdot}65 \times 10^{-16}$	$1{\cdot}90 \times 10^{-18}$	$6{\cdot}42 \times 10^{-23}$	...	...	$1{\cdot}17 \times 10^{-12}$	$9{\cdot}33 \times 10^{-12}$
300	$1{\cdot}52 \times 10^{-13}$	$1{\cdot}99 \times 10^{-22}$	$2{\cdot}25 \times 10^{-22}$	$2{\cdot}18 \times 10^{-25}$	...	...	...	$1{\cdot}52 \times 10^{-13}$	$3{\cdot}42 \times 10^{-12}$
400	$2{\cdot}31 \times 10^{-14}$	...	...	...	...	...	...	$2{\cdot}31 \times 10^{-14}$	$1{\cdot}29 \times 10^{-12}$
600	$5{\cdot}69 \times 10^{-16}$	...	...	...	...	...	...	$5{\cdot}69 \times 10^{-16}$	$1{\cdot}99 \times 10^{-13}$
800	$1{\cdot}75 \times 10^{-17}$	...	...	...	...	...	...	$1{\cdot}75 \times 10^{-17}$	$3{\cdot}43 \times 10^{-14}$
1000	$6{\cdot}4 \times 10^{-19}$	...	...	...	...	...	...	$6{\cdot}4 \times 10^{-19}$	$6{\cdot}48 \times 10^{-15}$

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TABLE VII.—Partial Densities of Atmospheric Constituents, in Grammes per c.c., for the case $H_1 = 30$ k.

Height in kilometres.	Helium.	Neon.	Nitrogen.	Oxygen.	Argon.	Krypton.	Xenon.	Total.	(Hydrogen.)
30	$1{\cdot}046 \times 10^{-11}$	$1{\cdot}606 \times 10^{-10}$	$1{\cdot}410 \times 10^{-5}$	$4{\cdot}33 \times 10^{-6}$	$2{\cdot}428 \times 10^{-7}$	$5{\cdot}23 \times 10^{-9}$	$9{\cdot}4 \times 10^{-10}$	$1{\cdot}87 \times 10^{-5}$	$1{\cdot}30 \times 10^{-11}$
40	$8{\cdot}45^{-12}$	$5{\cdot}48^{-11}$	$3{\cdot}165^{-6}$	$7{\cdot}85^{-7}$	$2{\cdot}89^{-8}$	$6{\cdot}23^{-11}$	$8{\cdot}6^{-13}$	$3{\cdot}98^{-6}$	$1{\cdot}16^{-11}$
60	$5{\cdot}53^{-12}$	$6{\cdot}44^{-12}$	$1{\cdot}616^{-7}$	$2{\cdot}62^{-8}$	$4{\cdot}17^{-10}$	$9{\cdot}28^{-13}$	$7{\cdot}9^{-19}$	$1{\cdot}88^{-7}$	$9{\cdot}42^{-12}$
80	$3{\cdot}63^{-12}$	$7{\cdot}68^{-13}$	$8{\cdot}42^{-9}$	$8{\cdot}97^{-10}$	$6{\cdot}19^{-12}$	$1{\cdot}46^{-18}$	$7{\cdot}9^{-25}$	$9{\cdot}33^{-9}$	$7{\cdot}62^{-12}$
100	$2{\cdot}39^{-12}$	$9{\cdot}24^{-14}$	$4{\cdot}46^{-10}$	$3{\cdot}13^{-11}$	$9{\cdot}40^{-14}$	$2{\cdot}40^{-22}$	...	$4{\cdot}80^{-10}$	$6{\cdot}17^{-12}$
106	$2{\cdot}11^{-12}$	$4{\cdot}91^{-14}$	$1{\cdot}854^{-10}$	$1{\cdot}15^{-11}$	$2{\cdot}69^{-14}$	...	...	$1{\cdot}99^{-10}$	$5{\cdot}80^{-12}$
110	$1{\cdot}94^{-12}$	$3{\cdot}23^{-14}$	$1{\cdot}037^{-10}$	$5{\cdot}90^{-12}$	$1{\cdot}17^{-14}$	...	...	$1{\cdot}11^{-10}$	$5{\cdot}56^{-12}$
120	$1{\cdot}58^{-12}$	$1{\cdot}13^{-14}$	$2{\cdot}400^{-11}$	$1{\cdot}11^{-12}$	$1{\cdot}47^{-15}$	...	...	$2{\cdot}67^{-11}$	$5{\cdot}00^{-12}$
130	$1{\cdot}28^{-12}$	$3{\cdot}97^{-15}$	$5{\cdot}64^{-12}$	$2{\cdot}12^{-13}$	$1{\cdot}86^{-16}$	...	...	$7{\cdot}14^{-12}$	$4{\cdot}51^{-12}$
140	$1{\cdot}04^{-12}$	$1{\cdot}40^{-15}$	$1{\cdot}319^{-12}$	$4{\cdot}03^{-14}$	$2{\cdot}35^{-17}$	...	...	$2{\cdot}40^{-12}$	$4{\cdot}06^{-12}$
150	$8{\cdot}48^{-13}$	$4{\cdot}93^{-16}$	$3{\cdot}12^{-13}$	$7{\cdot}76^{-15}$	$3{\cdot}76^{-18}$	...	...	$1{\cdot}168^{-12}$	$3{\cdot}66^{-12}$
200	$3{\cdot}05^{-13}$	$2{\cdot}86^{-18}$	$2{\cdot}45^{-16}$	$2{\cdot}17^{-18}$	$1{\cdot}11^{-23}$	...	...	$3{\cdot}05^{-13}$	$2{\cdot}19^{-12}$
300	$4{\cdot}18^{-14}$	$1{\cdot}04^{-22}$	$2{\cdot}03^{-22}$	$2{\cdot}49^{-25}$	...	...	...	$4{\cdot}18^{-14}$	$8{\cdot}00^{-13}$
400	$6{\cdot}05^{-15}$	...	...	...	...	...	...	$6{\cdot}05^{-15}$	$3{\cdot}02^{-13}$
600	$1{\cdot}49^{-16}$	...	...	...	...	...	...	$1{\cdot}49^{-16}$	$4{\cdot}67^{-14}$
800	$4{\cdot}52^{-18}$	...	...	...	...	...	...	$4{\cdot}52^{-18}$	$7{\cdot}99^{-15}$
1000	$1{\cdot}66^{-19}$	...	...	...	...	...	...	$1{\cdot}66^{-19}$	$1{\cdot}51^{-15}$

TABLE VIII.—Partial Densities of Atmospheric Constituents, in Grammes per c.c., for the case $H_1 = 50$ k.

Height in kilometres.	Helium.	Neon.	Nitrogen.	Oxygen.	Argon.	Krypton.	Xenon.	Total.	(Hydrogen.)
50	$4{\cdot}75 \times 10^{-13}$	$7{\cdot}29 \times 10^{-12}$	$6{\cdot}40 \times 10^{-7}$	$1{\cdot}967 \times 10^{-7}$	$1{\cdot}102 \times 10^{-8}$	$2{\cdot}37 \times 10^{-10}$	$4{\cdot}2 \times 10^{-11}$	$8{\cdot}48 \times 10^{-7}$	$5{\cdot}94 \times 10^{-13}$
60	$3{\cdot}84^{-13}$	$2{\cdot}50^{-13}$	$1{\cdot}45^{-7}$	$3{\cdot}61^{-8}$	$1{\cdot}33^{-9}$	$2{\cdot}91^{-12}$	$4{\cdot}1^{-17}$	$1{\cdot}82^{-7}$	$5{\cdot}34^{-13}$
80	$2{\cdot}52^{-13}$	$2{\cdot}98^{-13}$	$7{\cdot}55^{-9}$	$1{\cdot}23^{-9}$	$1{\cdot}97^{-11}$	$4{\cdot}58^{-16}$	$4{\cdot}1^{-20}$	$8{\cdot}80^{-9}$	$4{\cdot}32^{-13}$
100	$1{\cdot}66^{-13}$	$3{\cdot}60^{-14}$	$4{\cdot}00^{-10}$	$4{\cdot}29^{-11}$	$3{\cdot}00^{-13}$	$7{\cdot}60^{-20}$	...	$4{\cdot}43^{-10}$	$3{\cdot}50^{-13}$
106	$1{\cdot}46^{-13}$	$1{\cdot}91^{-14}$	$1{\cdot}657^{-10}$	$1{\cdot}57^{-11}$	$8{\cdot}50^{-14}$	...	...	$1{\cdot}82^{-10}$	$3{\cdot}28^{-13}$
110	$1{\cdot}35^{-13}$	$1{\cdot}26^{-14}$	$9{\cdot}24^{-11}$	$8{\cdot}06^{-12}$	$3{\cdot}73^{-14}$	...	...	$1{\cdot}006^{-10}$	$3{\cdot}15^{-13}$
120	$1{\cdot}09^{-13}$	$4{\cdot}40^{-15}$	$2{\cdot}15^{-11}$	$1{\cdot}52^{-12}$	$4{\cdot}67^{-15}$	...	...	$2{\cdot}31^{-11}$	$2{\cdot}83^{-13}$
130	$8{\cdot}90^{-14}$	$1{\cdot}54^{-15}$	$5{\cdot}035^{-12}$	$2{\cdot}895^{-13}$	$5{\cdot}90^{-16}$	...	...	$5{\cdot}41^{-12}$	$2{\cdot}55^{-13}$
140	$7{\cdot}24^{-14}$	$5{\cdot}45^{-16}$	$1{\cdot}189^{-12}$	$5{\cdot}57^{-14}$	$7{\cdot}54^{-17}$	...	...	$1{\cdot}32^{-12}$	$2{\cdot}30^{-13}$
150	$5{\cdot}90^{-14}$	$1{\cdot}93^{-16}$	$2{\cdot}81^{-13}$	$1{\cdot}07^{-14}$	$9{\cdot}64^{-18}$	...	...	$3{\cdot}51^{-13}$	$2{\cdot}07^{-13}$
200	$2{\cdot}125^{-14}$	$1{\cdot}11^{-18}$	$2{\cdot}19^{-16}$	$2{\cdot}97^{-18}$	$3{\cdot}57^{-22}$	...	...	$2{\cdot}15^{-14}$	$1{\cdot}14^{-13}$
300	$2{\cdot}90^{-15}$	$4{\cdot}71^{-23}$	$1{\cdot}85^{-22}$	$3{\cdot}50^{-25}$	...	...	...	$2{\cdot}90^{-15}$	$4{\cdot}54^{-14}$
400	$4{\cdot}20^{-16}$	...	...	...	...	...	...	$4{\cdot}20^{-16}$	$1{\cdot}71^{-14}$
600	$1{\cdot}03^{-17}$	...	...	...	...	...	...	$1{\cdot}03^{-17}$	$2{\cdot}64^{-15}$
800	$3{\cdot}13^{-19}$	...	...	...	...	...	...	$3{\cdot}13^{-19}$	$4{\cdot}51^{-16}$
1000	$1{\cdot}15^{-20}$	...	...	...	...	...	...	$1{\cdot}15^{-20}$	$8{\cdot}56^{-17}$

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Numerical Results. Tables of Density, Pressure and Composition.

§ 5. The partial densities of the various atmospheric constituents at various heights are given in Tables V.-VIII., which correspond to $H_1 = 12$, 20, 30, 50 k. respectively. These tables were calculated from formula (6) with the aid of the data of Table III. The total density at each height is given in the last column but one, and the last column gives the partial density of hydrogen if present in the proportion previously mentioned. It is to be noted that the total density is calculated on the assumption that hydrogen is absent. The total densities for the various values of H_1 are collected for comparison in Table IX.

TABLE IX.—Summary of Total Densities. (Hydrogen absent.)

Height in kilometres.	Height at which diffusion commences (H_1).			
	12	20	30	50
12	$3{\cdot}05 \times 10^{-4}$	$3{\cdot}05 \times 10^{-4}$	$3{\cdot}05 \times 10^{-4}$	$3{\cdot}05 \times 10^{-4}$
20	$8{\cdot}77^{-5}$	$8{\cdot}79^{-5}$	$8{\cdot}79^{-5}$	$8{\cdot}79^{-5}$
30	...	...	$1{\cdot}87^{-5}$	...
40	$4{\cdot}05^{-6}$	$4{\cdot}02^{-6}$	$3{\cdot}98^{-6}$	$3{\cdot}98^{-6}$
50	...	...	...	$8{\cdot}48^{-7}$
60	$1{\cdot}96^{-7}$	$1{\cdot}93^{-7}$	$1{\cdot}88^{-7}$	$1{\cdot}82^{-7}$
80	$9{\cdot}88^{-9}$	$9{\cdot}68^{-9}$	$9{\cdot}33^{-9}$	$8{\cdot}80^{-9}$
100	$5{\cdot}34^{-10}$	$5{\cdot}08^{-10}$	$4{\cdot}80^{-10}$	$4{\cdot}43^{-10}$
106	$2{\cdot}34^{-10}$	$2{\cdot}14^{-10}$	$1{\cdot}99^{-10}$	$1{\cdot}82^{-10}$
110	$1{\cdot}41^{-10}$	$1{\cdot}22^{-10}$	$1{\cdot}11^{-10}$	$1{\cdot}006^{-10}$
120	$4{\cdot}45^{-11}$	$3{\cdot}25^{-11}$	$2{\cdot}67^{-11}$	$2{\cdot}31^{-11}$
130	$2{\cdot}05^{-11}$	$1{\cdot}10^{-11}$	$7{\cdot}14^{-12}$	$5{\cdot}41^{-12}$
140	$1{\cdot}31^{-11}$	$5{\cdot}41^{-12}$	$2{\cdot}40^{-12}$	$1{\cdot}32^{-12}$
150	$9{\cdot}76^{-12}$	$3{\cdot}57^{-12}$	$1{\cdot}168^{-12}$	$3{\cdot}51^{-13}$
200	$3{\cdot}40^{-12}$	$1{\cdot}17^{-12}$	$3{\cdot}05^{-13}$	$2{\cdot}15^{-14}$
300	$4{\cdot}46^{-13}$	$1{\cdot}52^{-13}$	$4{\cdot}18^{-14}$	$2{\cdot}90^{-15}$
400	$6{\cdot}69^{-14}$	$2{\cdot}31^{-14}$	$6{\cdot}05^{-15}$	$4{\cdot}20^{-16}$
600	$1{\cdot}65^{-15}$	$5{\cdot}69^{-16}$	$1{\cdot}49^{-16}$	$1{\cdot}03^{-17}$
800	$4{\cdot}95^{-17}$	$1{\cdot}75^{-17}$	$4{\cdot}52^{-18}$	$3{\cdot}13^{-19}$
1000	$1{\cdot}82^{-18}$	$6{\cdot}4^{-19}$	$1{\cdot}66^{-19}$	$1{\cdot}15^{-20}$

Table X. shows the total pressures, both excluding and including hydrogen. The partial pressures of the different constituents were first calculated from the partial densities of Tables V.-VIII., by making use of the multiplying factors of Table IV., and the total pressures were obtained by addition. Table XI. shows the number of molecules per c.c. of the various constituents, and the total number for the case $H_1 = 20$ k.; it was calculated by means of the factors of Table IV.

Lastly, Tables XII., XIII. give the percentage composition of the air, by mass and by volume, at various heights in the case $H_1 = 20$ k. The percentages are given to the nearest 0·1. The tables refer to argon, nitrogen, oxygen and helium only, but the remaining constituents taken together never amount to 0·05 per cent. Hydrogen is supposed to be absent.

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TABLE X.—Pressures at various Heights in Dynes per Square Centimetre.

The column headed W quotes the pressures given by Wegener on the assumption of the presence of geo-coronium.

(Note, 1 millibar = 10^3 dynes/sq. cm. = 0·75 mm.)

Height in kilometres.	Hydrogen absent. Height at which diffusion commences (H_1).				Hydrogen present. Height at which diffusion commences (H_1).				W
	12	20	30	50	12	20	30	50	11
0	$1{\cdot}014 \times 10^{6}$	$1{\cdot}014 \times 10^{6}$	$1{\cdot}014 \times 10^{6}$	$1{\cdot}014 \times 10^{6}$	...	...	...	...	$1{\cdot}013 \times 10^{6}$
12	$1{\cdot}92 \times 10^{5}$	$1{\cdot}92 \times 10^{5}$	$1{\cdot}92 \times 10^{5}$	$1{\cdot}92 \times 10^{5}$	...	...	...	...	...
20	$5{\cdot}55 \times 10^{4}$	$5{\cdot}53 \times 10^{4}$	$5{\cdot}53 \times 10^{4}$	$5{\cdot}53 \times 10^{4}$	...	...	...	...	$5{\cdot}56 \times 10^{4}$
30	...	...	$1{\cdot}17 \times 10^{4}$	...	Same as for hydrogen absent				...
40	$2{\cdot}58 \times 10^{3}$	$2{\cdot}55 \times 10^{3}$	$2{\cdot}52 \times 10^{3}$	$2{\cdot}52 \times 10^{3}$					$2{\cdot}56 \times 10^{3}$
50	...	...	...	$5{\cdot}33 \times 10^{2}$					...
60	$1{\cdot}26 \times 10^{2}$	$1{\cdot}24 \times 10^{2}$	$1{\cdot}20 \times 10^{2}$	$1{\cdot}15 \times 10^{2}$	$1{\cdot}27 \times 10^{2}$	...	...	...	$1{\cdot}41 \times 10^{2}$
80	$6{\cdot}52 \times 10^{0}$	$6{\cdot}27 \times 10^{0}$	$6{\cdot}01 \times 10^{0}$	$5{\cdot}62 \times 10^{0}$	$7{\cdot}45 \times 10^{0}$	$6{\cdot}56 \times 10^{0}$	$6{\cdot}07 \times 10^{0}$	...	$2{\cdot}56 \times 10^{1}$
100	$4{\cdot}49 \times 10^{-1}$	$3{\cdot}63 \times 10^{-1}$	$3{\cdot}19 \times 10^{-1}$	$2{\cdot}85 \times 10^{-1}$	$1{\cdot}20 \times 10^{0}$	$6{\cdot}01 \times 10^{-1}$	$3{\cdot}75 \times 10^{-1}$	$2{\cdot}88 \times 10^{-1}$	$1{\cdot}71 \times 10^{1}$
106	$2{\cdot}43 \times 10^{-1}$	$1{\cdot}69 \times 10^{-1}$	$1{\cdot}37 \times 10^{-1}$	$1{\cdot}17 \times 10^{-1}$	$9{\cdot}50 \times 10^{-1}$	$3{\cdot}93 \times 10^{-1}$	$1{\cdot}89 \times 10^{-1}$	$1{\cdot}20 \times 10^{-1}$	...
110	$1{\cdot}75 \times 10^{-1}$	$1{\cdot}08 \times 10^{-1}$	$7{\cdot}97 \times 10^{-2}$	$6{\cdot}52 \times 10^{-2}$	$8{\cdot}53 \times 10^{-1}$	$3{\cdot}23 \times 10^{-1}$	$1{\cdot}30 \times 10^{-1}$	$6{\cdot}90 \times 10^{-2}$	...
120	$9{\cdot}74 \times 10^{-2}$	$4{\cdot}44 \times 10^{-2}$	$2{\cdot}34 \times 10^{-2}$	$1{\cdot}54 \times 10^{-2}$	$7{\cdot}07 \times 10^{-1}$	$2{\cdot}37 \times 10^{-1}$	$6{\cdot}86 \times 10^{-2}$	$1{\cdot}80 \times 10^{-2}$	$1{\cdot}41 \times 10^{1}$
130	$6{\cdot}88 \times 10^{-2}$	$2{\cdot}62 \times 10^{-2}$	$9{\cdot}62 \times 10^{-3}$	$3{\cdot}84 \times 10^{-3}$	$6{\cdot}19 \times 10^{-1}$	$2{\cdot}00 \times 10^{-1}$	$5{\cdot}04 \times 10^{-2}$	$6{\cdot}15 \times 10^{-3}$	...
140	$5{\cdot}42 \times 10^{-2}$	$1{\cdot}91 \times 10^{-2}$	$5{\cdot}62 \times 10^{-3}$	$1{\cdot}14 \times 10^{-3}$	$5{\cdot}51 \times 10^{-1}$	$1{\cdot}75 \times 10^{-1}$	$4{\cdot}23 \times 10^{-2}$	$3{\cdot}22 \times 10^{-3}$	$1{\cdot}20 \times 10^{1}$
150	$4{\cdot}31 \times 10^{-2}$	$1{\cdot}49 \times 10^{-2}$	$4{\cdot}07 \times 10^{-3}$	$4{\cdot}58 \times 10^{-4}$	$4{\cdot}89 \times 10^{-1}$	$1{\cdot}56 \times 10^{-1}$	$3{\cdot}72 \times 10^{-2}$	$2{\cdot}33 \times 10^{-3}$	...
200	$1{\cdot}55 \times 10^{-2}$	$5{\cdot}62 \times 10^{-3}$	$1{\cdot}39 \times 10^{-3}$	$9{\cdot}69 \times 10^{-5}$	$2{\cdot}83 \times 10^{-1}$	$9{\cdot}16 \times 10^{-2}$	$2{\cdot}12 \times 10^{-2}$	$2{\cdot}09 \times 10^{-3}$	$7{\cdot}76 \times 10^{0}$
300	$2{\cdot}03 \times 10^{-3}$	$6{\cdot}99 \times 10^{-4}$	$1{\cdot}91 \times 10^{-4}$	$1{\cdot}32 \times 10^{-5}$	$9{\cdot}96 \times 10^{-2}$	$3{\cdot}16 \times 10^{-2}$	$7{\cdot}42 \times 10^{-3}$	$5{\cdot}43 \times 10^{-4}$	$4{\cdot}39 \times 10^{0}$
400	$3{\cdot}05 \times 10^{-4}$	$1{\cdot}05 \times 10^{-4}$	$2{\cdot}76 \times 10^{-5}$	$1{\cdot}92 \times 10^{-6}$	$3{\cdot}70 \times 10^{-2}$	$1{\cdot}18 \times 10^{-2}$	$2{\cdot}76 \times 10^{-3}$	$1{\cdot}57 \times 10^{-4}$	$2{\cdot}94 \times 10^{0}$
600	$7{\cdot}52 \times 10^{-6}$	$2{\cdot}59 \times 10^{-6}$	$6{\cdot}80 \times 10^{-7}$	$4{\cdot}70 \times 10^{-8}$	$5{\cdot}69 \times 10^{-3}$	$1{\cdot}80 \times 10^{-3}$	$4{\cdot}23 \times 10^{-4}$	$2{\cdot}39 \times 10^{-5}$	...
800	$2{\cdot}26 \times 10^{-7}$	$7{\cdot}97 \times 10^{-8}$	$2{\cdot}06 \times 10^{-8}$	$1{\cdot}43 \times 10^{-9}$	$9{\cdot}67 \times 10^{-4}$	$3{\cdot}10 \times 10^{-4}$	$7{\cdot}22 \times 10^{-5}$	$4{\cdot}08 \times 10^{-7}$	...
1000	$8{\cdot}30 \times 10^{-9}$	$2{\cdot}92 \times 10^{-9}$	$7{\cdot}57 \times 10^{-10}$	$5{\cdot}25 \times 10^{-11}$	$1{\cdot}83 \times 10^{-4}$	$5{\cdot}86 \times 10^{-5}$	$1{\cdot}36 \times 10^{-5}$	$7{\cdot}73 \times 10^{-7}$	...

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TABLE XI.—NUMBER OF MOLECULES PER C.C. OF VARIOUS ATMOSPHERIC CONSTITUENTS FOR THE CASE $H_1 = 20\ k$.

Height in kilometres.	Helium.	Neon.	Nitrogen.	Oxygen.	Argon.	Krypton.	Xenon.	Total.	Hydrogen.
0	$1{\cdot}06 \times 10^{14}$	$3{\cdot}27 \times 10^{14}$	$2{\cdot}08 \times 10^{19}$	$5{\cdot}58 \times 10^{18}$	$2{\cdot}52 \times 10^{17}$	$2{\cdot}58 \times 10^{15}$	$2{\cdot}9 \times 10^{14}$	$2{\cdot}66 \times 10^{19}$	$2{\cdot}68 \times 10^{14}$
12	$2{\cdot}63 \times 10^{13}$	$7{\cdot}99 \times 10^{13}$	$5{\cdot}06 \times 10^{18}$	$1{\cdot}36 \times 10^{18}$	$6{\cdot}12 \times 10^{16}$	$6{\cdot}34 \times 10^{14}$	$7{\cdot}15 \times 10^{13}$	$6{\cdot}48 \times 10^{18}$	$6{\cdot}52 \times 10^{13}$
20	$7{\cdot}59 \times 10^{12}$	$2{\cdot}31 \times 10^{13}$	$1{\cdot}460 \times 10^{18}$	$3{\cdot}92 \times 10^{17}$	$1{\cdot}76 \times 10^{16}$	$1{\cdot}83 \times 10^{14}$	$2{\cdot}07 \times 10^{13}$	$1{\cdot}87 \times 10^{18}$	$1{\cdot}89 \times 10^{13}$
40	$4{\cdot}97^{12}$	$2{\cdot}68^{12}$	$7{\cdot}32^{16}$	$1{\cdot}29^{16}$	$2{\cdot}48^{14}$	$2{\cdot}58^{10}$	$1{\cdot}76^{7}$	$8{\cdot}63^{16}$	$1{\cdot}52^{13}$
60	$3{\cdot}24^{12}$	$3{\cdot}15^{11}$	$3{\cdot}76^{15}$	$4{\cdot}31^{14}$	$3{\cdot}60^{12}$	$3{\cdot}88^{6}$	$1{\cdot}63^{1}$	$4{\cdot}19^{15}$	$1{\cdot}23^{12}$
80	$2{\cdot}13^{12}$	$3{\cdot}76^{10}$	$1{\cdot}956^{14}$	$1{\cdot}47^{13}$	$5{\cdot}35^{10}$	$6{\cdot}05^{2}$	$1{\cdot}63^{-5}$	$2{\cdot}125^{14}$	$9{\cdot}90^{12}$
100	$1{\cdot}40^{12}$	$4{\cdot}55^{9}$	$1{\cdot}037^{13}$	$5{\cdot}16^{11}$	$8{\cdot}18^{8}$	$1{\cdot}02^{-1}$	...	$1{\cdot}23^{13}$	$8{\cdot}05^{12}$
106	$1{\cdot}23^{12}$	$3{\cdot}67^{9}$	$4{\cdot}32^{12}$	$1{\cdot}89^{11}$	$2{\cdot}35^{8}$	...	...	$5{\cdot}73^{12}$	$7{\cdot}55^{12}$
110	$1{\cdot}14^{12}$	$1{\cdot}59^{9}$	$2{\cdot}41^{12}$	$9{\cdot}73^{10}$	$10{\cdot}22^{7}$	...	...	$3{\cdot}65^{12}$	$7{\cdot}25^{12}$
120	$9{\cdot}26^{11}$	$5{\cdot}56^{8}$	$5{\cdot}60^{11}$	$1{\cdot}84^{10}$	$1{\cdot}27^{7}$	...	...	$1{\cdot}504^{12}$	$6{\cdot}52^{12}$
130	$7{\cdot}53^{11}$	$1{\cdot}92^{8}$	$1{\cdot}314^{11}$	$3{\cdot}48^{9}$	$1{\cdot}605^{6}$	...	...	$8{\cdot}87^{11}$	$5{\cdot}87^{12}$
140	$6{\cdot}13^{11}$	$6{\cdot}90^{7}$	$3{\cdot}09^{10}$	$6{\cdot}69^{8}$	$2{\cdot}07^{5}$	...	...	$6{\cdot}45^{11}$	$5{\cdot}29^{12}$
150	$4{\cdot}98^{11}$	$2{\cdot}45^{7}$	$7{\cdot}32^{9}$	$1{\cdot}29^{8}$	$2{\cdot}61^{4}$	...	...	$5{\cdot}05^{11}$	$4{\cdot}97^{12}$
200	$1{\cdot}81^{11}$	$1{\cdot}42^{5}$	$5{\cdot}82^{6}$	$3{\cdot}66^{4}$	$9{\cdot}91^{-1}$	...	...	$1{\cdot}805^{11}$	$2{\cdot}92^{12}$
300	$2{\cdot}35^{10}$	$6{\cdot}08^{0}$	$4{\cdot}94^{0}$	$4{\cdot}19^{-3}$	...	...	...	$2{\cdot}35^{10}$	$1{\cdot}04^{12}$
400	$3{\cdot}56^{9}$	...	...	...	...	...	...	$3{\cdot}56^{9}$	$3{\cdot}95^{11}$
600	$8{\cdot}78^{7}$	...	...	...	...	...	...	$8{\cdot}78^{7}$	$6{\cdot}08^{10}$
800	$2{\cdot}70^{6}$	...	...	..	...	...	...	$2{\cdot}70^{6}$	$1{\cdot}05^{10}$
1000	$9{\cdot}9^{4}$	...	...	...	...	...	...	$9{\cdot}9^{4}$	$1{\cdot}98^{9}$

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TABLE XII.—Percentages (by Mass) of principal Atmospheric Constituents for the case $H_1 = 20$ k.

(The remaining constituents never exceed 0·05 per cent.[1])

Height in kilometres.	Helium.	Nitrogen.	Oxygen.	Argon.
20	...	75·5	23·2	1·3
40	...	82·9	16·7	0·4
60	0·0	88·3	11·6	0·1
80	0·1	92·0	7·9	0·0
100	1·7	93·0	5·3	...
106	3·7	91·7	4·6	...
110	6·1	89·8	4·1	...
120	18·4	78·7	2·9	...
130	44·2	54·2	1·6	...
140	73·4	26·0	0·6	...
150	90·5	9·3	0·2	...
200	100·0	0·0	0·0	...
300	100·0	...	...	...
400	100·0	...	..	...
600	100·0	...	...	...
800	100·0	...	...	...
1000	100·0	...	...	...

[1] Except CO_2. *Vide* § 4.

TABLE XIII.—Percentages (by Volume) of principal Atmospheric Constituents for the case $H_1 = 20$ k.

Height in kilometres.	Helium.	Nitrogen.	Oxygen.	Argon.
20	...	78·1	21·0	0·9
40	...	84·8	14·9	0·3
60	0·1	89·8	10·0	0·1
80	1·0	92·0	7·0	0·0
100	11·4	84·4	4·2	...
106	21·4	75·3	3·3	...
110	31·3	66·0	2·7	...
120	61·6	37·2	1·2	...
130	84·8	14·8	0·4	...
140	95·1	4·8	0·1	...
150	98·6	1·4	0·0	...
200	100·0	0·0	...	...
300	100·0	...	...	...
400	100·0	...	...	...
600	100·0	...	...	...
800	100·0	...	...	...
1000	100·0	...	...	...

General Description of the Variation with Height of the Density, Pressure and Composition of the Atmosphere.

§ 6. The variation of the total density and pressure with height is best seen from Figs. 1 and 2, where the logarithms of these quantities are plotted. It is at once apparent that up to roughly 100 k. it is practically immaterial at what height convective mixing ceases and the constituents separate out by diffusion, at least so far as the density and pressure are

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concerned. Above 100 k., however, the pressure and density are

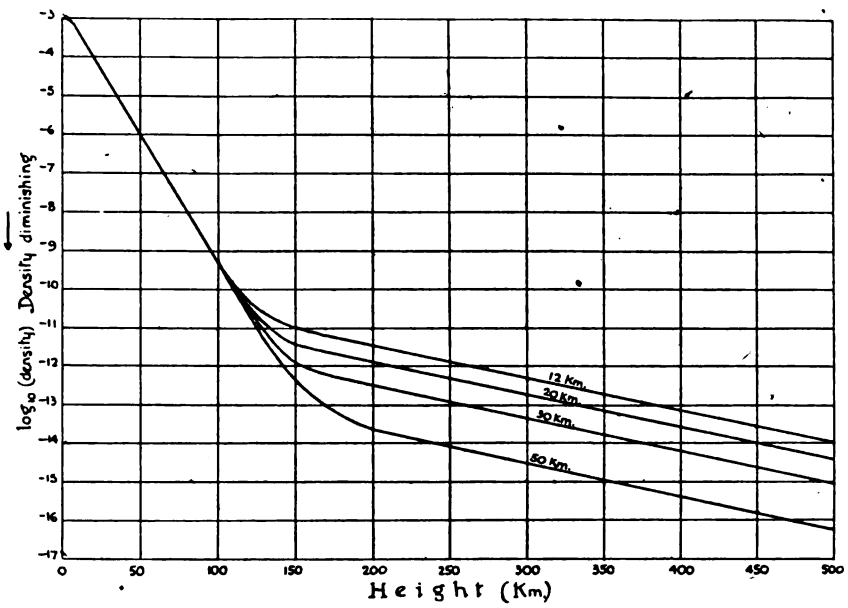

FIG. 1.—Curves showing variation of the density of the atmosphere with height, in the cases where diffusion commences at 12, 20, 30 and 50 k. respectively. (Plotted from Table IX.) The density is in grammes per c.c.

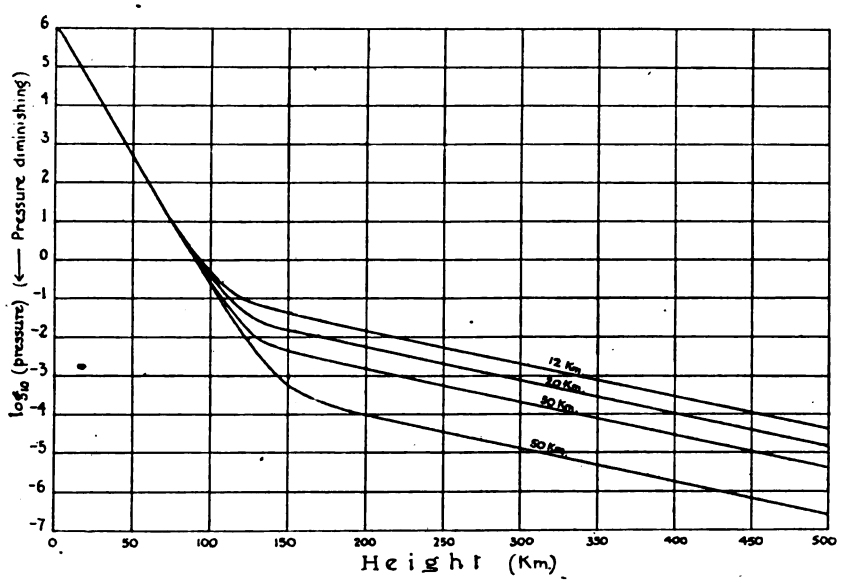

FIG. 2.—Curves showing variation of the pressure of the atmosphere with height, in the cases where diffusion commences at 12, 20, 30 and 50 k. respectively. (Plotted from Table X.) The pressure is in dynes per sq. cm.

sensitive to the exact height at which diffusion commences; it is seen,

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for example, that above 200 k. a change of H_1 from 12 k. to 50 k. reduces the density and pressure more than a hundredfold.

Each curve of the logarithm of the density or pressure against the height consists of two almost straight portions[1] inclined at an angle to each other, and connected by an arc of much greater curvature in the region 100 to 200 k. This implies that the density and pressure vary nearly exponentially up to 100 k., and then, again, beyond 200 k.; for the lower values of H_1 the variations are practically exponential above 150 k. The bends in the curves are more sudden for the smaller values of H_1 than for the larger. This confirms what was arrived at above theoretically, namely, that the separation is more rapid the smaller is H_1. It is easily seen, in fact, that the first long straight piece on each curve corresponds to an oxy-nitrogen mixture in which the proportions do not differ largely from the proportions in the troposphere. At first these two elements separate only slowly, owing to the small difference between their molecular weights; and owing to their large proportions in the base of the stratosphere they control the total density. However, at about 100 k. the oxygen begins to give place to helium, which rapidly displaces first the oxygen and then the nitrogen; the second long straight piece on each curve thus corresponds to an atmosphere of almost pure helium. The height at which separation by diffusion commences regulates the rapidity with which the oxygen and nitrogen are supplanted by the helium. The suddenness[2] of the transition from the oxy-nitrogen atmosphere to the helium atmosphere is due to the large interval between the molecular weights of oxygen and nitrogen and that of helium.

The change in composition with height is shown pictorially in Fig. 3, in which the results of Tables XII., XIII., are plotted. These diagrams are almost self-explanatory. Any horizontal line drawn on one of the diagrams is divided into a number of segments by the curves and the bounding verticals; the lengths of these segments measure the percentages of the constituents, according to the areas in which they lie. Above about 175 k. the proportions (by volume) of the constituents other than helium are too small to be shown on the scale taken, and above this height the atmosphere is almost all helium.[3] For $H_1 = 20$ k., nitrogen attains its maximum proportion (by volume) at 80 k.

The presence in the atmosphere of a constituent lighter than helium would seriously alter our estimates of the pressure and density. It will be seen from Tables V. to VIII. that if hydrogen were present, its partial density would exceed the combined density of all the other constituents above a height of 120 to 150 k. At 1000 k. the density of the hydrogen atmosphere would be about 10^4 times the density of the helium atmosphere. The effect on the pressure is of at least the same order of magnitude; this is shown in Table X., where the total pressures, for hydrogen absent and hydrogen present, are given. At 150 k., for example (taking $H_1 = 20$ k.), the pressure when hydrogen is present is ten times that when hydrogen is absent; at 100 k. it is twice, and at 1000 k. it is 2×10^4 times. Perhaps more striking still is a comparison

[1] The first portion is not straight in the interval 0–12 k., owing to the temperature variation in this region.

[2] The suddenness of the change is also pointed out by Wegener, *loc. cit.* It is, of course, more pronounced still if hydrogen and geo-coronium are assumed to be present.

[3] This mode of representation is used by Dewar (*loc. cit.*) and Wegener.

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of these pressures with those calculated by Wegener[1] on the assumption of the presence of geo-coronium, of molecular weight 0·4; these (reduced from mm. to dynes per sq. cm.) are quoted in Table X. in the column headed W. At 100 k. it is seen that the pressure of a geo-coronium atmosphere is about 40 times that of an atmosphere containing neither hydrogen nor geo-coronium; at 140 k. the ratio is 200, at 400 k. it is 10,000.

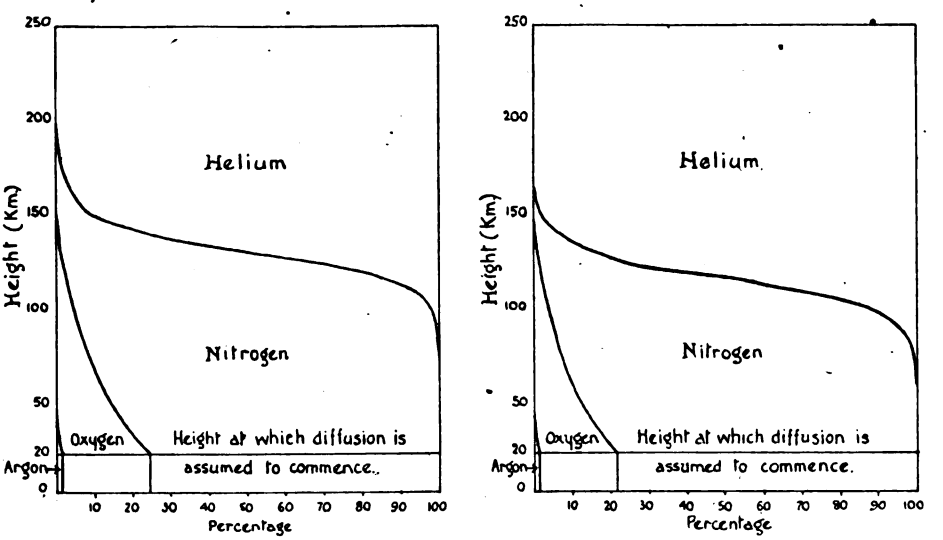

FIG. 3.—Diagrammatic representation of the composition of the air at various heights. If a horizontal line is drawn, corresponding to any given height, the lengths of the intercepts made on it by the curves give the proportions of the different constituents.

The general conclusions to be drawn from these results are:

(1) atmospheric phenomena originating and occurring below 100 k. height may be expected to be independent of the height at which diffusion commences and of the presence of light constituents in the atmosphere;

(2) phenomena occurring slightly above 100 k. will be roughly independent of the height at which diffusion commences, and of the presence of hydrogen, but might be affected by the presence of constituents lighter than hydrogen;

(3) phenomena occurring above 150 k. should depend largely both on the height at which diffusion commences and on the presence of light constituents such as hydrogen.

The conclusions are naturally restricted to phenomena dependent on the density, the pressure or the composition. It may be pointed out that an experimental determination of the pressure[2] or density of the atmosphere at a height above 100 or 150 k., could such be made, would afford valuable indications as to the composition of the atmosphere, and at sufficiently great heights might afford information as to the mean

[1] *Thermodyn. d. Atmosph.*, p. 46.

[2] *E.g.* from the persistence of the meteor trails (see p. 360, footnote).

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height at which diffusion may be supposed to commence. A high pressure or density implies the presence of light constituents; or, the composition being given, it implies that diffusion starts at a low height. The extent to which the atmosphere reaches would also indicate whether light constituents were present; the lighter the top constituent, the less rapidly its density falls off and the greater the distance at which there is an appreciable atmosphere. It may be reiterated here that it is the molecular weights of the constituents, and not the proportions in which they occur in the troposphere, that determine, in the main, the structure of the atmosphere.

Penetration of the Atmosphere by α-Particles.

§ 7. We have seen that certain properties of the atmosphere change most rapidly in the layer 100 to 150 k. It is a remarkable fact that it is in this same layer that the phenomena of aurorae are observed to occur; to be more precise, aurorae appear to be confined entirely to the layer 100 to 130 k.; they occur most frequently towards the base of the layer, there being two well-defined maxima at 100 k. and 106 k. Though a discussion of the origin of aurorae would be outside the province of this paper, it is of interest to investigate the bearing of the calculation already made on a theory that has been advanced to account for aurorae—the theory, namely, that aurorae are the manifestation of the absorption by the earth's atmosphere of α-particles emitted by the sun. If this theory is accepted, a rough explanation of the observed height of aurorae immediately suggests itself; we may anticipate that the α-particles penetrate the outer helium atmosphere with considerable ease, but that the layer 100 to 150 k., in which the rate of increase of density is suddenly augmented, acts to them as a brake, so that the extra resistance they encounter prevents them from continuing their careers below 100 k. We shall accordingly examine more closely the numerical magnitudes involved to see if this speculation is borne out.

It is necessary to recapitulate a few of the properties of α-particles. That aurorae were due to some kind of solar radiation had been often suggested, but it was Vegard[1] who showed that many of the observed features of aurorae could be explained by assuming that the radiation in question consisted of α-particles similar to those emitted by radio-active substances. The α-particles are charged helium atoms, initially propelled with velocities of the order of $1{\cdot}5 \times 10^9$ to $2{\cdot}0 \times 10^9$ cm. per sec. They must be supposed to penetrate the earth's atmosphere, describing curved paths[2] under the influence of the earth's magnetic field but remaining practically undeflected by collisions until their velocity is reduced to the ordinary velocity of thermal agitation of the surrounding air molecules. During their passage through the atmosphere they both ionise it and render it luminous, just as the air in the neighbourhood of a radio-active substance is ionised and rendered luminous. It is the luminosity, of course, which constitutes the aurorae; but the existence of an ionised layer at auroral heights, too, is suggested by recent studies of magnetic storms. The extra brilliance of the lower

[1] *Phil. Mag.*, *London*, **13**, 1912, p. 211.

[2] Investigated by Störmer.

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extremities of aurorae is explained by one of the characteristic properties of α-particles; α-particles traversing a gas and having a definite initial velocity have a definite range in that gas, beyond which no ionisation can be detected, and the ionisation produced is most intense just before the end of the range. The brilliant lower edge of an auroral form thus corresponds to the neighbourhood surrounding the extremity of the range of the α-particles in the atmosphere.

In any given gas there is a definite relation between the velocity of an α-particle at any moment and the distance it has yet to travel before completing its range, so that given the total range of an α-particle in the gas it is possible to deduce its initial velocity. We can therefore attempt to determine the initial velocity with which α-particles would have to be projected into the earth's atmosphere in order that their range should just extend to the bottom of the auroral layer. This has already been done by Vegard,[1] but his results were based on Wegener's calculations; they will be quoted later.

α-Particles.—The quantitative properties of α-particles which are required are as follows:

(1) For a given initial velocity and a given gas the range is such that the mass of gas traversed per unit area is constant.

(2) For a given gas under given conditions the connection between velocity (V) and range (r) is [2]

$$V^3 = ar, \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where a is a constant.

(3) The "stopping powers" or absorbing powers of different elements are such that the masses per unit area required to stop the α-particle to the same extent are proportional to the square roots of the atomic weights.[3]

(4) For a mixture of gases each atom must be supposed to exercise independently its own stopping power, this being calculated from the square root law.

The effect of these laws is that we can calculate the mass of air which is equivalent, as regards stopping power, to any given gas mixture (homogeneous or heterogeneous) by means of the following formula. Let A_s be the atomic weight of an element occurring in the mixture, M_s the total mass of this element per unit area in the layer considered; let M be the "equivalent" mass of air per unit area, A the "atomic weight" of air, which may be taken as 14·4. Then M is given by

$$\frac{M}{A^{\frac{1}{2}}} = \sum_s \frac{M_s}{A_s^{\frac{1}{2}}}. \quad . \quad . \quad . \quad . \quad . \quad (12)$$

From this mass per unit area we can calculate the corresponding length of the air column under given conditions of temperature and pressure, and this length will be the "air-range" equivalent to the layer of gas-mixture considered. Finally the velocity corresponding to this air range can be found from the formula $V^3 = ar$, given that $r = 7{\cdot}06$ cm., $V = 2{\cdot}06 \times 10^9$ cm. per sec. are corresponding values[4] for air at 20° C.

[1] *Loc. cit.* [2] Geiger, *Phil. Mag.*, *London*, **1**, 1906.

[3] Bragg and Kleeman, *Phil. Mag.*, *London*, **10**, 1905, p. 318.

[4] These are the air-range and initial velocity of the α-particles from Ra C. See Rutherford, *Radio-active Substances and their Radiations*, 1916, p. 164.

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and 760 mm. (The density of air under these conditions is $1{\cdot}205 \times 10^{-3}$ grammes per c.c., so that $r = M \times 10^3/1{\cdot}205$.)

Calculations for the Atmosphere.—In estimating the equivalent air-range for α-particles, penetrating the atmosphere from the outside, we shall ignore the curvature of their paths and assume that they approach the earth normally (thus getting a lower limit for the velocity required for any given penetration). We then require the total mass per unit area of the various atmospheric constituents above given heights.

A rough approximation to the mass of each constituent above a given height would of course be obtained by dividing its partial pressure at that height by the value of g at the same height. The true mass per unit area is given by

$$\int_z^{z_1} \rho_s \, dz,$$

where z_1 is the height of the outer limit of the atmosphere. The expression for ρ_s given by equation (10), § 3, cannot be integrated in finite terms, and recourse must be had to quadrature. Though equation (10) gives values for ρ_s which do not tend to zero as z tends to infinity, this is due to the failure of the assumptions made, for large values of z, and in particular to the neglect of rotation, and in practice it is sufficient to continue the integration to heights above which the contributions to the integrals even for fairly large intervals are quite small. Tables XIV. and XV. below were obtained by numerical

TABLE XIV.—Calculated for $H_1 = 20$ K. Total Masses of various Atmospheric Constituents above given Heights in Grammes per sq. cm.

(Similar figures are added for hydrogen, and for any hypothetical constituent X, of molecular weight half that of hydrogen, if supposed to be present in the lower atmosphere in the same proportion by volume as the assumed amount of hydrogen.)

Height in kilometres.	Argon.	Oxygen.	Nitrogen.	Helium.	Hydrogen.	X.
600	...	...	...	$3{\cdot}28 \times 10^{-9}$	$2{\cdot}21 \times 10^{-4}$	$3{\cdot}37 \times 10^{-5}$
400	...	...	...	$1{\cdot}25^{-7}$	$1{\cdot}39^{-5}$	$1{\cdot}01^{-4}$
300	...	...	...	$8{\cdot}12^{-7}$	$3{\cdot}57^{-5}$	$1{\cdot}59^{-4}$
200	...	$1{\cdot}19 \times 10^{-12}$	$1{\cdot}90 \times 10^{-10}$	$5{\cdot}82^{-6}$	$9{\cdot}46^{-5}$	$2{\cdot}55^{-4}$
150	...	$4{\cdot}10^{-9}$	$2{\cdot}33^{-7}$	$1{\cdot}59^{-5}$	$1{\cdot}56^{-4}$	$3{\cdot}23^{-4}$
140	$6{\cdot}46 \times 10^{-12}$	$2{\cdot}12^{-8}$	$9{\cdot}76^{-7}$	$1{\cdot}95^{-5}$	$1{\cdot}72^{-4}$	$3{\cdot}40^{-4}$
130	$5{\cdot}08^{-11}$	$1{\cdot}10^{-7}$	$4{\cdot}09^{-6}$	$2{\cdot}39^{-5}$	$1{\cdot}91^{-4}$	$3{\cdot}56^{-4}$
120	$4{\cdot}04^{-10}$	$5{\cdot}75^{-7}$	$1{\cdot}75^{-5}$	$2{\cdot}93^{-5}$	$2{\cdot}11^{-4}$	$3{\cdot}73^{-4}$
110	$3{\cdot}19^{-9}$	$3{\cdot}04^{-6}$	$7{\cdot}47^{-5}$	$3{\cdot}69^{-5}$	$2{\cdot}33^{-4}$	$3{\cdot}92^{-4}$
106	$7{\cdot}32^{-9}$	$5{\cdot}90^{-6}$	$1{\cdot}34^{-4}$	$3{\cdot}90^{-5}$	$2{\cdot}43^{-4}$	$4{\cdot}00^{-4}$
100	$2{\cdot}55^{-8}$	$1{\cdot}61^{-5}$	$3{\cdot}23^{-4}$	$4{\cdot}42^{-5}$	$2{\cdot}59^{-4}$	$4{\cdot}14^{-4}$
80	$1{\cdot}66^{-6}$	$4{\cdot}56^{-4}$	$6{\cdot}06^{-3}$	$1{\cdot}10^{-4}$	$3{\cdot}17^{-4}$	$4{\cdot}57^{-4}$
60	$1{\cdot}11^{-4}$	$1{\cdot}33^{-3}$	$1{\cdot}155^{-1}$	$1{\cdot}01^{-4}$	$3{\cdot}89^{-4}$	$5{\cdot}04^{-4}$
40	$7{\cdot}65^{-3}$	$3{\cdot}94^{-1}$	$2{\cdot}25^{0}$	$1{\cdot}54^{-4}$	$4{\cdot}79^{-4}$	$5{\cdot}58^{-4}$
20	$5{\cdot}34^{-1}$	$1{\cdot}19^{+1}$	$4{\cdot}44^{+1}$	$2{\cdot}34^{-4}$	$5{\cdot}89^{-4}$	$6{\cdot}19^{-4}$
12	$2{\cdot}34^{0}$	$4{\cdot}43^{+1}$	$1{\cdot}50^{+2}$	$3{\cdot}12^{-4}$	$6{\cdot}86^{-4}$	$6{\cdot}67^{-4}$
0	$1{\cdot}32^{+1}$	$2{\cdot}38^{+2}$	$7{\cdot}82^{+2}$	$7{\cdot}81^{-4}$	$1{\cdot}27^{-3}$	$9{\cdot}60^{-4}$

quadrature of the densities already given in Table V. to VIII. As the curve of log ρ_s against z is so nearly straight, the quadrature is best effected by dividing the curve into intervals such that the arc contained in each may be regarded as actually straight; this is equivalent to using the formula

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$$\int_a^b f(x)dx = \frac{(b-a)}{2{\cdot}3026} \cdot \frac{f(b)-f(a)}{\log_{10}f(b)-\log_{10}f(a)},$$

which is exact when $f(x) = Ae^{kx}$, and in practice this formula was applied directly. In the case of hydrogen and "X" (see below) the integration was continued only to 1000 k. and a small correction made for the mass remaining above. It is believed that the figures represent the masses per unit area sufficiently accurately, at least to the extent justified by the original assumptions. In the case $H_1 = 20$ k. the masses of the partial constituents were obtained separately, and the total mass obtained by addition; for the other values of H_1, the total density itself was integrated, and accordingly the figures are not quite so accurate owing to the large curvature of a part of the curve of log ρ.

Table XIV. gives the total mass per unit area of the principal atmospheric constituents, for $H_1 = 20$ k. Table XV. gives the combined

TABLE XV.—Total Mass of Air above given Heights in Grammes per sq. cm. for various Values of H_1.

(Hydrogen is assumed to be absent.)

Height in kilometres.	$H_1 = 12$ k.	$H_1 = 20$ k.	$H_1 = 30$ k.	$H_1 = 50$ k.
400	$3{\cdot}62 \times 10^{-7}$	$1{\cdot}25 \times 10^{-7}$	$3{\cdot}27 \times 10^{-8}$	$2{\cdot}31 \times 10^{-9}$
300	$3{\cdot}41^{-6}$	$8{\cdot}12^{-7}$	$2{\cdot}18^{-7}$	$1{\cdot}70^{-8}$
200	$1{\cdot}79^{-5}$	$5{\cdot}82^{-6}$	$1{\cdot}54^{-6}$	$1{\cdot}08^{-7}$
150	$4{\cdot}81^{-5}$	$1{\cdot}61^{-5}$	$4{\cdot}78^{-6}$	$6{\cdot}99^{-7}$
140	$5{\cdot}94^{-5}$	$2{\cdot}05^{-5}$	$6{\cdot}47^{-6}$	$1{\cdot}43^{-6}$
130	$7{\cdot}58^{-5}$	$2{\cdot}81^{-5}$	$1{\cdot}08^{-5}$	$4{\cdot}33^{-6}$
120	$1{\cdot}07^{-4}$	$4{\cdot}74^{-5}$	$2{\cdot}57^{-5}$	$1{\cdot}65^{-5}$
110	$1{\cdot}90^{-4}$	$1{\cdot}15^{-4}$	$8{\cdot}47^{-5}$	$6{\cdot}90^{-5}$
106	$2{\cdot}64^{-4}$	$1{\cdot}79^{-4}$	$1{\cdot}45^{-4}$	$1{\cdot}24^{-4}$
100	$4{\cdot}82^{-4}$	$3{\cdot}83^{-4}$	$3{\cdot}37^{-4}$	$3{\cdot}01^{-4}$
80	$6{\cdot}89^{-3}$	$6{\cdot}62^{-3}$	$6{\cdot}30^{-3}$	$5{\cdot}89^{-3}$
60	$1{\cdot}32^{-1}$	$1{\cdot}29^{-1}$	$1{\cdot}25^{-1}$	$1{\cdot}20^{-1}$
40	$2{\cdot}67^{0}$	$2{\cdot}65^{0}$	$2{\cdot}61^{0}$	$2{\cdot}58^{0}$
20	$5{\cdot}71^{+1}$	$5{\cdot}69^{+1}$	$5{\cdot}68^{1}$	$5{\cdot}68^{+1}$
12	$1{\cdot}965^{+2}$	$1{\cdot}961^{+2}$	$1{\cdot}96^{2}$	$1{\cdot}96^{+2}$
0	$1{\cdot}033^{+3}$	$1{\cdot}033^{+3}$	$1{\cdot}033^{+3}$	$1{\cdot}033^{+3}$

mass of all constituents, for $H_1 = 12$, 20, 30, 50 k., Table XVI. their relative percentages. Table XVII. gives the equivalent air-ranges for an α-particle penetrating to heights of 106, 100, 80 k. It is calculated from Table XIV. for $H_1 = 20$ k., and from similar tables for the other values of H_1, formula (12) being employed. In this calculation it is found to be necessary only to take into account helium, nitrogen and oxygen. The corresponding initial velocities of the α-particles, calculated from formula (11), are also shown. Table XVIII. provides corresponding figures for the case when hydrogen is assumed to be present, the air-ranges equivalent to the hydrogen being shown separately. Table XIX. quotes the standard air-ranges and initial velocities for various radio-active substances. Lastly, Table XX. is a copy of that given by Vegard.[1]

Results.—The general result of these calculations appears to be that α-particles, entering the outer fringe of the earth's atmosphere with

[1] *Loc. cit.*

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velocities of the same magnitude as the observed velocities with which α-particles are expelled from radio-active substances, could penetrate to a height of 85 or 80 k.; the slowest could penetrate nearly to 85 k., the

TABLE XVI.—Total Masses per Unit Area of various Constituents, above given Heights, expressed as Percentages of the Total Mass of all Constituents per Unit Area.

(Calculated from Table XIV.) ($H_1 = 20$ k.)

Height in kilometres.	Helium.	Nitrogen.	Oxygen.	Argon.
600	100·0	...	...	...
400	100·0	...	...	...
300	100·0	...	...	...
200	100·0	0·0	...	...
150	98·6	1·4	0·0	...
140	95·1	4·8	0·1	...
130	85·0	14·6	0·4	...
120	61·8	37·0	1·2	...
110	32·1	65·2	2·7	...
106	21·8	74·9	3·3	...
100	11·6	84·2	4·2	...
80	1·7	91·4	6·9	0·0
60	0·1	89·5	10·3	0·1
40	0·0	84·8	14·9	0·3
20	...	78·1	21·0	0·9
12	...	76·3	22·5	1·2
0	...	75·7	23·0	1·3

TABLE XVII.—Equivalent Air-Ranges for α-Particles penetrating to given Heights, and Corresponding Initial Velocities.

(Hydrogen absent.) (The air-ranges correspond to air at 760 mm. and 20° C.)

Height in kilo-metres.	$H_1 = 12$ k.		$H_1 = 20$ k.		$H_1 = 30$ k.		$H_1 = 50$ k.	
	r (cms.).	V (cms./sec.).	r.	V.	r.	V.	r.	V.
106	0·31	$\cdot72 \times 10^9$	0·18	$\cdot61 \times 10^9$	0·13	$\cdot54 \times 10^9$	·105	$\cdot51 \times 10^9$
100	0·50	·85 ,,	0·36	·76 ,,	0·29	·71 ,,	·25	·63 ,,
80	5·95	1·94 ,,	5·59	1·90 ,,	5·32	1·87 ,,	4·94	1·82 ,,

TABLE XVIII.—Equivalent Air-Ranges for α-Particles penetrating to given Heights, and Corresponding Initial Velocities.

(Hydrogen present.) ($H_1 = 20$ k.)

Height in kilometres.	Equivalent range without hydrogen.	Equivalent range for hydrogen.	Total equivalent range.	V.
106	0·183	0·772	0·955	$1·06 \times 10^9$
100	0·356	0·814	1·17	1·12 ,,
80	5·59	0·998	6·59	2·01 ,,

fastest to just below 80 k. This result is independent of the height at which diffusion commences, and of the presence or absence of hydrogen, in accordance with the general conclusions of § 6. Vegard's results,

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however, differ considerably from ours. Using the pressures calculated by Wegener (which as we have seen are very large compared with those obtained by rejecting the hypothesis of geo-coronium), he finds that an α-particle with the initial velocity of those from RaC could penetrate to only 200 k.; to penetrate to 100 k. a velocity would be required larger than any yet observed for α-particles emitted in radio-active processes.

TABLE XIX.—Air-Ranges and Initial Velocities of α-Particles for various Representative Radio-active Substances.

(Quoted from Rutherford, *Rad. Substances*, etc., p. 164.)

Substance.	Air Range (15° C.) (cm.).	V (cm. per sec.).
Uranium 1 . . .	2·50	$1·45 \times 10^9$
Uranium 2 . . .	2·90	1·53 ,,
Radium	3·30	1·61 ,,
Ra Emanation . .	4·16	1·73 ,,
Ra. C.	6·94	2·06 ,,
Thorium	2·72	1·50 ,,

The column headed X in Table XIV. gives the mass per unit area of a hypothetical constituent, of molecular weight half that of hydrogen, if present in the troposphere in the amount assumed for hydrogen; this, as we have seen, is the lightest constituent that the atmosphere could retain, and the masses given in column X may therefore be regarded as the maximum additional mass per unit area which unknown constituents could contribute. Even this, however, if converted

TABLE XX.—Vegard's Table of Velocities of α-Particles required to penetrate to given Heights (*Phil. Mag., London*, 1912, p. 211).

V_a is the velocity, assuming the stopping power of the matter traversed is that of air.
V_H is the velocity, assuming the stopping power of the matter traversed is that of hydrogen.

Height in kilometres.	Pressure (mm.).	V_a.		V_H.	
500	·00162	0·62 V_0	$1·24 \times 10^9$,,	0·97 V_0	$1·94 \times 10^9$,,
300	·00329	0·79 ,,	1·58 ,,	1·24 ,,	2·48 ,,
200	·00581	0·96 ,,	1·92 ,,	1·50 ,,	3·0 ,,
100	·0128	1·24 ,,	2·48 ,,	1·94 ,,	3·9 ,,
60	0·106	1·51 ,,	5·02 ,,	...	...
20	41·7	(18·4) ,,	(36·8) ,,	...	...
0	760·	(48·4) ,,	(96·8) ,,	...	...

Note (1) V_0 = vel. of α-particles from RaC = 2×10^9 cms. per sec. (2) The pressures used are those given by Wegener, calculated on the assumption of the presence of hydrogen and geo-coronium.

into an equivalent air-range, only adds an additional 1·8 cm. of air-range at 100 k., and so does not invalidate the order of magnitude of our results. The large differences between these results and Vegard's well illustrate the effect of admitting the existence, even in very small proportions, of a very light constituent in the atmosphere.

The equivalent air-range down to 100 k. appears to be of the order of $\frac{3}{4}$ cm.; in view of the fact that aurorae are not found below 100 k.

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this seems very small. If the α-particle hypothesis is correct, then either the particles are largely retarded during their passage through the sun's atmosphere (some retardation, of course, is to be expected) or the assumptions on which the calculations are based imply too low densities at great heights. If the assumptions are correct, it would seem that the α-particles would be almost at the end of their range (in the ordinary sense) on leaving the sun's atmosphere. It must be remembered, however, that some allowance must be made for the obliquity of path of the particles through the earth's atmosphere.[1] It will be noticed that owing to the cube law, the rate of variation of velocity with range is small, so that, for example, the velocity to penetrate to 100 k. is as much as half that of the slowest α-particles, although the equivalent air-range to 100 k. is so small.

Ionisation by β- and γ-Radiation.

§ 8. We have seen that the layer of the atmosphere ionised by α-particles cannot extend below a height of 80 k.; the auroral phenomena, indeed, indicate that it does not extend below 100 k. This, however, does not exhaust the possibilities of ionised layers, and it has been suggested that between the heights mentioned and the ground there is a second ionised layer, probably ionised by some kind of ultra-violet radiation. The existence of such a layer has been predicted from the existence of the diurnal and semi-diurnal variations in the magnetic elements, for these can be accounted for by the assumption of a conducting layer moving through the earth's magnetic field, the origin of the motion being supposed to be partly tidal, partly thermal.

It seems, therefore, of interest to discuss the possibility of ionisation of the atmosphere by radiation other than α-particles, and we shall accordingly consider the absorption in the atmosphere of γ-rays (or X-rays) and β-rays. We shall discuss neither whether the atmosphere is actually subject to these radiations, nor their possible sources.

Absorption of γ-rays.—The very penetrating radiation known as γ-rays is absorbed by matter according to an exponential law (provided it is homogeneous). If I_0 is the initial intensity of a beam (as measured by the ionisation it can produce in an ionisation chamber), I the intensity after traversing a length l of matter, then it is found that

$$I = I_0 e^{-\mu l},$$

where μ is a constant depending on the absorbing matter employed and the "hardness" or source of the radiation. If, however, we express the result in the form

$$I = I_0 e^{-\lambda \rho l}, \qquad (13)$$

where ρ is the density of the absorbing material, then λ is found to be roughly independent of the nature of the matter traversed, though still

[1] One aspect of the flight of α-particles from the sun to the earth is of general physical interest. When their initial velocity is known, the time of flight from the sun to the earth can be calculated. If this time of flight could be verified by direct observation of the time-connection between aurorae (or magnetic storms) and events occurring on the sun, then we should have a direct observation of the *velocity* of an α-particle by measurement of its time of transit over a known distance. What is usually termed the "velocity" is not a rate of change of displacement but a magnitude expressing the relation of the "α-ray" to electromagnetic fields (*vide* Campbell, *Modern Electrical Theory*, p. 173).

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depending on the nature of the radiation. If the matter is heterogeneous, we replace ρl by

$$\int_0^l \rho dl.$$

This may also be written $m(l)$, where $m(l)$ denotes the total mass traversed per unit area at right angles to the path. Differentiating (13) we have

$$\begin{aligned} dI &= -\lambda I \rho dl \\ &= -\lambda I \rho dm, \end{aligned} \tag{14}$$

so that the absorption in any thin layer is proportional to the intensity of the radiation arriving at that layer and to the mass per unit area in the layer. Now it is found experimentally that the ionisation, produced by a given radiation in a given volume of gas is proportional to the density of that gas, approximately. Since this ionisation by definition is proportional also to the intensity of the radiation, it follows, as we should expect, that in (14) dI may be taken to be proportional to the actual ionisation, produced in the thin layer of thickness dl, during the transmission of the beam. Let $P(l)$ denote the ionisation at the point considered; then

$$\begin{aligned} P(l) &\propto I \rho dl \\ &\propto e^{-\lambda m(l)} \rho dl. \end{aligned}$$

Consider the application of this formula to the absorption of γ-rays by the atmosphere. The rays are supposed to be incident normal to the earth. Let $m(z)$ denote the total mass of gas per unit area above a height z. Then the ionisation at height z will be $P(z)$ given by

$$P(z) = k e^{-\lambda m(z)} \rho(z) dz \tag{15}$$

where k is some constant. The factor $e^{-\lambda m(z)}$ decreases as z decreases, whilst $\rho(z)$ increases as z decreases; the product is very small for large values of z and for small values of z, and it is easily seen that there is a certain height z at which the ionisation $P(z)$ is a maximum. Thus, if γ-rays are incident on the atmosphere, the resulting ionisation will increase down to a certain height z, thereafter decreasing, and the layer in the region of the maximum may be termed the layer of maximum conductivity. It is of interest to determine the height of this layer, and the mode of variation of the ionisation in its neighbourhood.

Differentiating (15) for a maximum we have

$$\frac{d\rho}{dz} - \lambda \rho \frac{dm}{dz} = 0,$$

or, since $\rho = dm/dz$, we have

$$\frac{1}{\rho^2} \frac{d\rho}{dz} = \lambda. \tag{16}$$

The value of z for which this holds gives the height of the layer of maximum conductivity. Below 100 k., before separation by diffusion has become serious, $\frac{1}{\rho} \frac{d\rho}{dz}$ is nearly constant, and thus $\rho(z) \propto 1/\lambda$. Thus the height of maximum conductivity is determined entirely by λ; now the value of λ fixes the hardness or penetrating power of the waves, the more penetrating rays having the smaller values of λ, whence it naturally follows that the height of maximum conductivity decreases as the hardness increases. This height, it should be noted, is independent

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of the previous history of the rays, *e.g.* of any absorption they may have undergone in the sun's atmosphere.

Numerical results.—The following is a selection of values of the absorption co-efficient λ for the γ-rays from various radio-active substances:

TABLE XXI.[1]

Substance.	λ.
Uranium X_1	8·9 and 0·26
Uranium X_2	0·052
Radium C	0·0424
Thorium D	0·035
Ordinary X-rays (average)	4

A very rough calculation of the expression $\frac{1}{\rho^2}\frac{d\rho}{dz}$ gives the following values (roughly independent of H_1).

TABLE XXII.

Height (z) (k.)	20	40	60	80	100
$\frac{1}{\rho^2}\frac{d\rho}{dz}$	0·0175	0·38	7·8	153	2860

A comparison of this with Table XX. shows at a glance where the maximum for any given radiation may be expected. The γ-rays emitted by radium preparations consist mostly of those from RaC, which are both intense and very penetrating. For the corresponding value of λ (0·0424) a more careful calculation indicates that the maximum ionisation occurs at a height of 26 k. The variation of ionisation in the neighbourhood of this, as given by (15) and the figures of Table XV., is shown in the following table:

TABLE XXIII.—Relative Ionisation for γ-rays (λ=·0424).

Height (k.)	12	20	26	30	40
Ionisation (relative).	$5·7\times10^{-3}$	$5·8\times10^{-1}$	1·00	$7·8\times10^{-1}$	$2·7\times10^{-1}$
Height (k.)	50	60		80	100
Ionisation (relative).	$6·0\times10^{-2}$	$1·4\times10^{-2}$		$7·2\times10^{-4}$	$3·8\times10^{-5}$

These figures are plotted in Fig. 4. It appears that the appreciable ionisation is confined to the layer extending from slightly below 20 k. to slightly above 50 k., and that the lower edge of the layer is more

[1] Rutherford and Richardson, *Phil. Mag., London*, 1913 and 1914. See also Kaye, *X-rays* (1918), p. 263.

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sharply defined than the upper. The ionisation at the ground is naturally inappreciable; calculation shows that it should be less than 10^{-19} times the maximum ionisation.

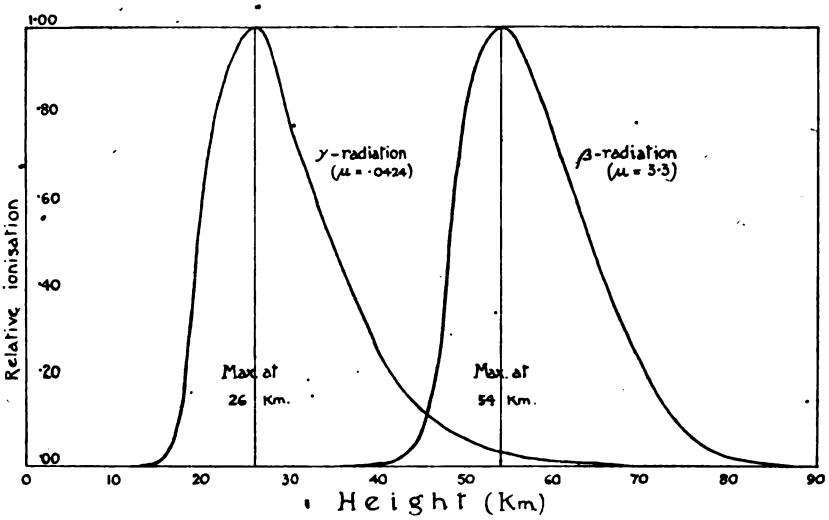

FIG. 4.—The ordinates are proportional to the absorption of the radiation at the various heights and hence give the ionisation.

Absorption of β-rays.—The penetrating power of β-rays is intermediate between those of α-rays and γ-rays. The absorption in matter of homogeneous beams of β-rays is a complicated phenomenon, but β-rays such as those ordinarily emitted by radium, which are of various initial velocities, are absorbed roughly according to an exponential law.[1] As with γ-rays, the absorption is roughly proportional to the density of the absorbing substance, and the ionisation produced in various gases is roughly proportional to the density of the gas, so that the same analysis applies as for γ-rays. The absorption coefficient λ is, however, not quite so constant for different materials. From figures given by Rutherford,[1] the value of λ in air for the β-rays from RaC comes out as 3·3 according to one determination; another determination, for the β-rays from RaB and RaC together, gives it as about 1·1.

Assuming $\lambda = 3{\cdot}3$ for definiteness it is found that the height of maximum ionisation is 54 k., and that the variation of ionisation in the neighbourhood of the maximum is as in the following table:

TABLE XXIV.—RELATIVE IONISATION FOR β-RAYS ($\lambda = 3{\cdot}3$).

Height (k.)	40	50	54	60	70	80	100
Ionisation (rel.)	$3{\cdot}9 \times 10^{-3}$	0·79	1·00	0·77	0·24	$5{\cdot}8 \times 10^{-2}$	$3{\cdot}1 \times 10^{-2}$

These figures are plotted in Fig. 4. The curve has the same general form as that for γ-rays, the layer of appreciable ionisation extending in this case from about 45 k. to 80 k.

[1] Rutherford, *Radio-active Substances* (1916).

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From the two curves drawn, the nature of the variation of ionisation for any intermediate value of λ can rapidly be estimated. It is seen that for all values of λ that can reasonably be expected, either for γ-rays or β-rays, the maximum will occur between 20 k. and 60 k.; for γ-rays, indeed, it is unlikely to be above 40 k. All these heights are well below the auroral layer, as had been previously anticipated from independent considerations.[1] The unexpected sharpness of the lower edge of the ionised layer is worthy of note.

It may be observed that in accordance with the conclusions of § 6, the numerical results of the present section are practically independent of the height at which diffusion commences and of the presence of light constituents.

Variation with latitude.—The height of the ionised layer just calculated refers to radiation incident normally. If the beam is so large that it embraces the whole earth, most of it will be incident obliquely and the absorption and consequently the height of the ionised layer will vary with the obliquity. Consider a small pencil of the beam which if continued to the surface of the earth would have an angle of incidence ϕ measured from the normal. Take a point on the beam at height z from the surface, and let y be the distance of this point from the earth, measured along the beam. Then it is clear that the position of maximum conductivity is given by

$$\frac{1}{\rho^2}\frac{d\rho}{dy} = \lambda$$

or

$$\frac{1}{\rho^2}\frac{d\rho}{dz}\frac{dz}{dy} = \lambda. \qquad (17)$$

The factor $\frac{dz}{dy}$ is clearly less than unity and decreases as ϕ increases; a simple calculation shows it to be equal to

$$\left\{1 - \left(\frac{a \sin \phi}{a+z}\right)^2\right\}^{\frac{1}{2}}.$$

It follows that as ϕ increases the height of maximum conductivity increases. The following table shows the variation of the height of the layer with ϕ, for γ- and β-rays.

TABLE XXV.—Height of Layer of Maximum Conductivity, for various Angles of Incidence ($H_1 = 20$ k.).

ϕ	0°	30°	50°	70°	80°	90°
γ-rays ($\lambda = 0424$)	26	26	28	32	36	40
β-rays ($\lambda = 3{\cdot}3$)	54	54	56	60	63	66

Table XXVI. shows the relative ionisation at various heights for γ-rays at grazing incidence ($\phi = 90°$), for which the maximum occurs at 40 k.

[1] Chapman, *Cambridge, Trans. Phil. Soc.*, **22**, 16 (1919).

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TABLE XXVI.—Relative Ionisation for γ-rays (λ = ·0424) at Grazing Incidence.

Height (k.)	20	30	40	50	60	80	100
Ionisation (relative)	10^{-12}	$7{\cdot}43 \times 10^{-2}$	1·00	$4{\cdot}68 \times 10^{-1}$	$1{\cdot}19 \times 10^{-1}$	$6{\cdot}19 \times 10^{-3}$	$3{\cdot}25 \times 10^{-4}$

If the above numbers are plotted as in Fig. 4, it is found that the curve is of much the same general shape, the lower boundary being more sharply defined than the upper; the range of appreciable ionisation extends from about 30 k. to 65 k. Thus if a parallel beam of γ-radiation is incident on the earth, the appreciable ionisation is confined to a nearly hemispherical shell of about 35 k. thickness, the height of maximum conductivity varying from 26 k. in the centre of the beam to 40 k. at the fringes.

Atmospheric Ozone.

§ 9. That traces of ozone are present in the atmosphere is well known, but the actual proportion is a matter of considerable uncertainty. Estimates have been made tending to show that in country air the proportion of ozone amounts to about 1½ parts by volume in a million; however, the methods used have frequently been very crude, as usually they detect the presence not only of ozone but also of other oxidisers such as hydrogen peroxide. The actual proportion may thus be much less than this; and over towns and places where oxidisable matter is present, ozone is absent.

The presence of ozone in the atmosphere has been confirmed by spectroscopic methods by Fowler and Strutt.[1] Certain absorption bands in the ultra-violet which occur in the spectra of Sirius and of the sun were shown to be identical with bands in the absorption spectrum of ozone. Moreover the intensity of the bands in the solar spectrum varied with the sun's altitude. The bands in the ozone spectrum could be obtained with quite small thicknesses of dilute ozone, of a concentration of not more than one per cent.

A certain amount of ozone may be produced in various ways at the surface of the earth, but we may also look for sources of ozone in the various phenomena occurring at great heights. Ozone is known to be produced by the action of ultra-violet light on oxygen; Regener[2] showed that ultra-violet light has both an ozonising and a de-ozonising effect, so that at a certain concentration of ozone a steady state is reached. Thus if the atmosphere contains a layer strongly ionised by ultra-violet radiation of some kind, the absorption of the radiation should make this layer in addition the seat of the production of ozone—a production, however, which would only reach certain small limits. The auroral layer may be another source of ozone. Ozone is always present near radio-active substances, as the Curies[3] first observed; it seems to be produced chiefly by the α-particles. If then aurorae are due to the absorption of α-particles, ozone should be produced, for at 100 k. there is still 5 per cent of oxygen according to Tables XII and XIII.

[1] *London, Proc. R. Soc.*, **93** (ser. A), 1917, p. 577.
[2] *Ann. Physik, Leipzig*, **20**, 1906, p. 1033.
[3] S. and P. Curie, *Paris, C. R. Acad. sci.*, **129**, 1899, p. 823.

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The production of ozone in any layer would lead to a slight increase in density in that layer, for the conversion of oxygen into ozone is accompanied with a contraction. The ozone as formed would diffuse both upwards and downwards—chiefly downwards, owing to the high molecular weight of ozone (half as much again as oxygen). At the same time the ozone would slowly dissociate into oxygen, so that the concentration would be expected to diminish as we recede in either direction from the layer in which it is produced. The resulting effect on the pressure and density at any point would most probably be very small.

It has been stated that the proportion of ozone near the ground increases with the height,[1] which would be in accordance with the above speculations as to the origin of ozone. By taking into account the rates of diffusion and of dissociation of ozone, it should be possible to calculate the relation between the concentration at any height and that at the layer where it is produced.

The Kinematical Viscosity of the Atmosphere.

§ 10. The "stiffness" of the atmosphere, or the resistance offered to large-scale convective motion between its parts, is measured by the coefficient of kinematical viscosity, which is the ratio of the ordinary coefficient of viscosity to the density. It is interesting to consider the way in which this varies with the height.

The viscosity usually considered in connection with a gas is the "molecular" viscosity, arising from the transfer of momentum across any plane by the agency of the moving molecules; the random motions of the molecules tend to convey momentum from the faster moving parts of the gas to the slower moving, with a result analogous to internal friction. However, the apparent viscosity of the air in the parts of the atmosphere near the ground, as indicated by the distribution of wind velocity with height, is much larger than the "molecular" viscosity determined experimentally, and it has been shown by Taylor[2] that the observed motion in the atmosphere can be accounted for more nearly by assuming that it is eddies many feet in diameter, rather than molecules, which act as carriers of momentum. From the observed variation of the magnitude and direction of the wind with height, it is possible to calculate the coefficient of "eddy viscosity," and in discussing the "stiffness" of the atmosphere it is clearly the eddy viscosity which must be adopted near the ground. The eddy viscosity depends on the amount of eddy motion present on any given occasion, and the following figures are extracted from the paper quoted:—

		Coeff. of kinematical eddy viscosity, in C.G.S. units.
Land	Strong winds	62×10^3
	Moderate winds	50×10^3
	Light winds	$\cdot 28 \times 10^3$
Sea (Certain regions)		$0{\cdot}77 \times 10^3$ to $6{\cdot}9 \times 10^3$

The ordinary coefficient of viscosity for air at the ground temperature is about $1{\cdot}77 \times 10^{-4}$, and on dividing by the density ($1{\cdot}25 \times 10^{-3}$)

[1] Wegener quotes Thierry for this, *loc. cit.*

[2] *London, Phil. Trans. R. Soc.*, **215** (ser. A), 1914, p. 1.

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we find 0·142 as the coefficient of kinematical viscosity. As the height increases, the coefficient of viscosity decreases, owing to the decreasing temperature, becoming $1{\cdot}42 \times 10^{-4}$ at 219°. The density, however, decreases more rapidly than this, and moreover continues to decrease when the temperature remains constant, so that the kinematical viscosity increases continually. The influence of change of composition of the atmosphere is only slight, for the separate coefficients of the constituents do not greatly differ. The following table gives the coefficients of viscosity of the principal constituents at 0° C. and at 219° a.; the next one (Table XXVIII.) gives the coefficients of kinematical viscosity at various heights, an approximate allowance being made for the change of composition.

TABLE XXVII.

	Coefficient of viscosity at	
	0° C.	−54° C. (219° a.).
Air	$1{\cdot}72 \times 10^{-4}$	$1{\cdot}46 \times 10^{-4}$
Nitrogen	$1{\cdot}66 \times 10^{-4}$	$1{\cdot}41 \times 10^{-4}$
Oxygen	$1{\cdot}89 \times 10^{-4}$	$1{\cdot}59 \times 10^{-4}$
Argon	$2{\cdot}10 \times 10^{-4}$	$1{\cdot}75 \times 10^{-4}$
Helium	$1{\cdot}89 \times 10^{-4}$	$1{\cdot}63 \times 10^{-4}$

TABLE XXVIII.—($H_1 = 20$ k.)

Height in kilometres.	Coefficient of viscosity (approx).	Density.	Coefficient of kinematic viscosity.
0	$1{\cdot}72 \times 10^{-4}$	$1{\cdot}25 \times 10^{-3}$	0·142
12	1·46	$3{\cdot}05 \quad -4$	0·479
20	1·46	$8{\cdot}79 \quad -5$	1·66
40	1·45	$4{\cdot}02 \quad -6$	$3{\cdot}6 \times 10^{1}$
60	1·44	$1{\cdot}93 \quad -7$	$7{\cdot}3 \times 10^{2}$
80	1·43	$9{\cdot}68 \quad -9$	$1{\cdot}48 \times 10^{4}$
100	1·44	$5{\cdot}08 \quad -10$	$2{\cdot}8 \times 10^{5}$
120	1·55	$3{\cdot}25 \quad -11$	$4{\cdot}8 \times 10^{6}$

The logarithms of the numbers in the last column of Table XXVIII. are shown plotted in Fig. 5 as a continuous line. Now the eddy viscosity may be expected to decrease with height, especially as the stratosphere is approached, so that as the height increases the effective viscosity of the air will approximate more and more to the molecular viscosity. The dotted curves in Fig. 5 suggest tentatively the way in which the eddy viscosity may be expected to vary (the only points really known on these curves are those for height zero). The effective viscosity of the air at all heights is then given by one of the dotted curves up to the point where it joins the continuous curve, thereafter by the continuous curve.

If the combined curve is approximately correct, the viscosity of the atmosphere suffers a remarkable drop between 10 and 20 k., and indeed does not recover its ground value until a height of 80 or 90 k. is reached; beyond this height the viscosity becomes very large. The fall

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in viscosity at certain heights may explain the curly meteor trails which have been observed.

A word may be added respecting the viscosity of gases at very low pressures. At ordinary pressures the viscosity of a gas is a function of the temperature only, but at pressures less than a millibar the viscosity, *as measured in the laboratory*, begins to decrease considerably. Sir W. Crookes,[1] for example, found that at 10^{-3} mb. the viscosity of air was less than one-sixth of that at 1 mb., and at lower pressures it decreased still more, tending to vanish as the pressure vanished. Now low pressures are actually attained in the atmosphere at quite moderate heights; at 100 k. the pressure is about 5×10^{-4} mb. However, it does

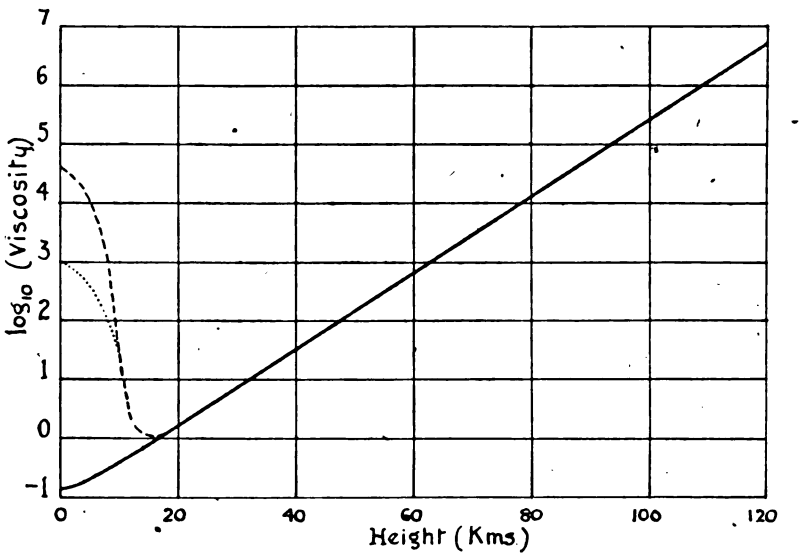

FIG. 5.—Variation of kinematical viscosity with height.
——— curve of ordinary (molecular) viscosity. ..... curves of eddy viscosity (conjectured).
(*Note.*—The ground value of the eddy viscosity is variable.)

not seem that the low experimental values can be legitimately applied to the viscosity of a gas so extensive in bulk as the atmosphere. Maxwell's law concerning the independence of viscosity and density breaks down at low pressures under experimental conditions, because the mean free path of the molecules becomes comparable with or greater than the dimensions of the apparatus, so that the molecules have not sufficient freedom adequately to transfer their momentum to other molecules by collision.[2] But in the upper atmosphere no such restriction exists. Even when the air is very rare and the mean free path accordingly very large, the normal value of the viscosity should hold provided sufficiently large volumes of gas are considered.

[1] *London, Phil. Trans. R. Soc.*, **172**, p. 378.
[2] See, *e.g.*, Jeans, *Dynamical Theory of Gases* (1916), p. 297.

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The Mean Free Path.

§ 11. Rough values of the mean free path in the atmosphere are provided by the following table. The mean free path for a single gas is given by the expression

$$\frac{1}{\sqrt{2}\pi\nu\sigma^2}$$

where σ is the molecular diameter. A mean value for σ of 3×10^{-8} has been taken, and no account has been paid to the circumstance that the air is a mixture.

TABLE XXIX.—Numbers of Molecules per c.c. and Mean Free Paths.
($H_1 = 20$ k.)

Height in kilometres.	Hydrogen Absent.		Hydrogen Present.	
	ν.	m.f.p. (cm.)	ν.	m.f.p. (cm.)
0	$2{\cdot}7 \times 10^{19}$	9×10^{-6}	$2{\cdot}7 \times 10^{19}$	9×10^{-6}
12	$6{\cdot}5^{18}$	4^{-5}	$6{\cdot}5^{18}$	4^{-5}
20	$1{\cdot}9^{18}$	1^{-4}	$1{\cdot}9^{18}$	1^{-4}
40	$8{\cdot}6^{16}$	3^{-3}	$8{\cdot}6^{16}$	3^{-3}
60	$4{\cdot}2^{15}$	6^{-2}	$4{\cdot}2^{15}$	6^{-2}
80	$2{\cdot}1^{14}$	1^{0}	$2{\cdot}2^{14}$	1^{0}
100	$1{\cdot}2^{13}$	2^{1}	$1{\cdot}3^{13}$	2^{1}
150	$5{\cdot}0^{11}$	5^{2}	$5{\cdot}3^{12}$	5^{1}
200	$1{\cdot}8^{11}$	1^{3}	$3{\cdot}1^{12}$	8^{1}
300	$2{\cdot}4^{10}$	1^{4}	$1{\cdot}1^{12}$	2^{2}
400	$3{\cdot}6^{9}$	7^{4}	$4{\cdot}0^{11}$	6^{2}
600	$8{\cdot}8^{7}$	3^{6}	$6{\cdot}1^{10}$	4^{3}
800	$2{\cdot}7^{6}$	9^{7}	$1{\cdot}1^{10}$	2^{4}
1000	$9{\cdot}9^{4}$	3^{9}	$2{\cdot}0^{9}$	1^{5}

It is seen that the mean free path is 1 cm. at 80 k. height, 100 metres at 300 k., 1000 k. at 800 k.; though these are much reduced at the greater heights if hydrogen is present. It is somewhat startling to observe that even at 800 k., where the mean free path is 1000 k., there are still 3,000,000 molecules per c.c.

Where the mean free path as calculated is so large that there is a considerable variation of density in a change of height equal to this distance, the calculated value gives no real indication of the average distance described by a molecule of this region before collision; the mean free path will be different in different directions, the calculated value (which is appropriate to a molecule moving horizontally) being intermediate between those for inward-moving and outward-moving molecules. From such a region a proportion of the outward-moving molecules will have no encounters whatever. But so long as attention is confined to a portion of the atmosphere in which the majority of the molecules collide with other molecules rather than describe undisturbed orbits, however large their free paths, so long will the ordinary coefficient of viscosity be appropriate.

Summary.

§ 12. In an undisturbed atmosphere at rest under gravity the various constituents do not remain uniformly mixed, but tend to separate out by

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diffusion, the heavier ones predominating below and the lighter above; at great heights only the lightest constituent will survive. In the earth's atmosphere the lightest constituent is hydrogen, and various writers have deduced that above 150 k. the atmosphere should consist entirely of hydrogen. A survey of the evidence shows, however, that the actual amount of hydrogen in the troposphere is very uncertain, and various reasons are adduced for seriously considering the tentative hypothesis that hydrogen is absent from the stratosphere. Comparative tables are given showing the pressure, density and composition at various heights for hydrogen present and hydrogen absent; in the latter case the atmosphere above 150 k. consists practically of helium. Criticism is made of Wegener's introduction of the hypothetical element geo-coronium.

The numerical results are used to make calculations of the extent to which the atmosphere could be penetrated from the outside by α-particles, β-particles, and γ-rays—types of radiation which theories of aurorae and magnetic storms have suggested may arrive from the sun. It is found that the fastest α-particles, if incident directly, would penetrate to about 80 k., which is a much greater penetration than that calculated by Vegard. It appears further that β-particles or γ-rays incident on the atmosphere would give rise to fairly definite layers of maximum ionisation, situated at heights of 54 k. and 26 k. respectively, and that these layers have comparatively sharp lower boundaries.

Finally, it is pointed out that the effective kinematical viscosity of the atmosphere increases very rapidly at great heights owing to the decrease in density.

DISCUSSION.

Sir NAPIER SHAW said the paper touched the general problem of meteorology where Prof. Chapman discussed the level at which diffusion began. That must be supposed to mean the level at which the ordinary causes of air mixture died away, and nothing but diffusion was left to promote mixture. It was quite possible that an attack on the subject from the point of view of the distribution of gases in relation to height would throw light upon the motion of gases in the top atmosphere. He did not think meteorological observations could contribute any definite statement as to the heights at which motion in the atmosphere began or ended. Prof. Chapman had mentioned wind as a cause of mixing. It was certain that in the stratosphere there were winds in different directions on different occasions and at different levels; the winds of those upper regions were probably extremely complicated. They might not be so complicated as regards the vertical as those down below, but there was very little reason for supposing that the horizontal winds were simplified.

Dr. C. CHREE referred to aurora. He was doubtful whether the two maxima for the lower limit of aurora at about 100 and 106 k. described by Vegard and Krogness were real. Vegard and Krogness themselves, and Störmer at an earlier date, had measured heights well under 90 k., though doubts were now expressed as to their accuracy. The absence of aurora from much lower levels could not be directly decided from photographs taken at the ends of a base as long as those recently used. The penetration of rays of different kinds had been dealt with previously by Vegard. The data in the paper applied apparently to rays travelling vertically. But according to Birkeland and Störmer the rays causing aurora might in part of their course be far from

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vertical. The level to which rays could penetrate would naturally be higher when the penetration was not direct. The difference in level of the upper and lower auroral limits was large. Thus if the spectrum were that of the gas at the level, exact measurements of the auroral spectrum at different levels, if obtainable, might throw a valuable light on the constitution of the upper atmosphere. It was interesting to have the calculations of Prof. Chapman and Mr. Milne to compare with those of Wegener.

Major J. ERSKINE-MURRAY, R.A.F., showed how the wireless waves travelled, and why it was that some stations never received from certain transmitting stations during the day, but did so at night, though a nearer station might receive equally at all times. The explanation lay in the way the wave travelled through the atmosphere and the position of the different stations with regard to the angle of reflection of the waves from the upper atmosphere. He had thus shown that a reflecting layer existed. Major Erskine-Murray drew Dr. de Groot's diagram on the board showing how the waves travelled round the earth by reflection from the upper atmosphere giving maximum strength of signals every 3000 k. The distance between these maxima showed that reflection took place at a height of 180 k. above the earth, a height which corresponded very well with the height of the interface between nitrogen and helium on Prof. Chapman's theory. In the tropics throughout the day the strength of signals had a most extraordinary sequence, there being two or more minima and maxima which depended on the altitude of the sun and the plane of incidence of the sun's rays. This showed that there was a definite connection between the direction of the sun's rays and the line of propagation of the wireless waves, and that refraction took place in the passage of a wave through intermediate layers of the atmosphere. Since the night effects were similar for all wave-lengths, reflection was indicated, but as during the day different wave-lengths were differently affected the action must in the latter case be of the nature of refraction. This refraction was apparently caused by layers of air having different densities of ionisation, which layers vary in position with the height of the sun.

Mr. J. S. DINES said that in referring to the diagram of auroral heights shown upon the screen Prof. Chapman had hinted that some of the isolated dots which lay in the upper part of the diagram, and thus indicated unusually high aurorae, might be due to errors of observation. He did not see why such errors should throw these dots up without throwing others down. The extremely well marked lower boundary of the dots seemed to show that there could not be much scattering due to observational error. In the same way Dr. Chree's suggestion that low aurorae might escape measurement with the long base line commonly used did not seem to afford any adequate explanation of the well-marked lower boundary.

Mr. W. H. DINES wrote that the only comment he had to make was about the temperature of the higher strata. There was observational evidence that the temperature from 13 to 20 k. over Europe was about 220 a., but in the absence of direct observation he did not think we were justified in assuming that the isothermal condition was maintained beyond 20 or 25 k. We might by so doing repeat in another form the old mistake of assuming without direct knowledge that the lapse rate, which we now know to be of limited extent, extended to the limit of the atmosphere.

Mr. E. A. MILNE, in reply to Sir Napier Shaw, said that it was not intended to convey the impression that there really existed a definite height at which mixing ceased and diffusion began; but this assumption was convenient for calculation, and by envisaging the consequences of variations in this height it was hoped to obtain limits between which the actual state of the atmosphere must lie. With regard to the assumed quiescence of the stratosphere, it was

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known that above the tropopause there was an appreciable falling off of the wind speed, on the average; at very great heights, the high viscosity would damp out motion very rapidly, but between, say, 100 k. and 120 k. the molecular viscosity appeared to be much smaller than the eddy viscosity near the ground, so that here the disturbance caused by quite a small body might take a considerable time to decay. In the absence of observational evidence, the assumption of the constancy of the temperature of the stratosphere could perhaps only be tested by an examination of the radiation interchanges at great heights, on the lines of Gold's investigation. In answer to Dr. Chree, the obliquity of the auroral rays did not necessarily cause much departure from the calculations in the paper, for practically the whole absorption occurred in quite a narrow layer; unless indeed, as in Vegard's latest theory, the streamers were caused by β-particles describing rapid convolutions round the lines of magnetic force, when the absorption due to the lateral motion might be large compared with the motion of penetration.

Sir NAPIER SHAW in returning the thanks of the Society to Prof. Chapman and Mr. Milne said that the paper would remain as a permanent record of the state of knowledge at this time. Though no claim was made in favour of any particular hypothesis, it was remarkable that so coherent and consistent a scheme could be founded on the assumption that there was no hydrogen in the upper layers of the atmosphere.

Analysis of Thermograph Readings registered at Fowley, Liphook, Hants.

We have received from Mr. E. A. Lee of Fowley, Liphook, a table of temperatures compiled from the readings of a thermograph during the ten years 1910–19. The instrument was placed in a Stevenson screen, 4 feet above the ground. The table sets out the number of hours during which the temperatures between certain limits were observed during each month of each year, and the figures given below summarise the information, omitting the number of hours between 32° and 60° F. During the ten years the number of hours of frost in each year varied from 392 in 1913 to 1190 in 1917. In 1910 no temperature above 80° F. was recorded, but in the following year 190 hours had readings above this limit, and 10 above 90° F. In May, frost was recorded in eight years, and in June for three hours in 1915.

Temperature Limits.	Number of hours (omitting fractions) recorded in										
	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	Total.
° F.											
Hours below 10	2	...	4	...	...	...	...	4	...	...	10
,, ,, 20	35	48	36	...	25	32	34	104	32	34	380
,, ,, 32	623	578	574	392	593	647	602	1082	549	810	6,450
,, above 60	1188	1741	1149	1378	1626	1441	1361	1511	1681	1398	14,474
,, ,, 70	129	659	146	249	442	234	259	332	303	367	3,120
,, ,, 80	...	180	30	16	46	8	17	23	17	29	366
,, ,, 90	...	10	...	...	...	...	...	...	...	...	10

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THE ETHER DIFFERENTIAL RADIOMETER.

By W. H. DINES, F.R.S., F.R.Met.Soc.

[Received February 26—Read June 16, 1920.]

THIS instrument has been designed for the purpose of finding the radiation from the sky by means of the equivalent radiative temperature of the sky, in the one way of using, directly, in the other way, indirectly. It consists essentially of a sensitive differential thermometer, upon the bulbs of which radiation from any part of the sky, or radiation from a full radiator at a given temperature, can be directed. In the direct way of using, the temperature of the artificial full radiator is altered until it produces exactly the same effect as the sky, and when this is attained it may be assumed that the equivalent radiative temperature of the sky is the same as that of the full radiator. In the indirect method of using the defect of radiation from the sky, which is cold, is compensated by radiation from a hot body falling on the same bulb, and by a simple calculation the equivalent temperature of the sky is deduced.

The differential thermometer is formed of two ordinary glass test tubes each containing a few drops of ether. The tubes communicate with each other by a U tube of about 0·7 mm. bore containing ether to form a pressure gauge. As the change of vapour pressure of ether is large for small changes of temperature the thermometer is very sensitive to small changes in the radiation falling on either bulb. It suffices to build up the thermometer with rubber stoppers to the test tubes. A completely sealed-up pair of bulbs nearly exhausted of air would no doubt be better, but would be very fragile and liable to break; but the rubber stoppers answer quite well and the ether will serve for months without renewing. Before the U tube is bent a glass hair should be pushed through its whole length and bent with it. The action of the hair is to prevent air bubbles remaining in the gauge.

The test tubes are mounted with their axes in one straight line, and round each tube a metal shield lagged outside with felt but with a longitudinal slit to admit radiation is arranged. The shield can turn round the common axis and thus admit radiation from any part of the same vertical plane, while there is a fair amount of symmetry about the supply of heat by convection to the two tubes. It is not desirable, however, that there should be a source of heat below or, so to speak, of cold above to produce convection currents. The test tubes and shields are mounted on a wooden frame in the base of which two holes are cut of sufficient size to clear the cone of radiation coming from either test tube. The frame stands on a trough of water at temperature T_t, and hence when the openings are directed downwards both test tubes are subject to radiation from a full radiator at temperature T_t.

A magnifying-glass can be added to detect more rapidly small motions of the liquid in the gauge.

To take a direct observation:

Call one test tube A and the other B. Direct both A and B towards the water in the trough (T_t) and wait until the liquid in the gauge is at rest. This should not take long since both tubes are subject to exactly

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the same heating conditions. Now turn A to the sky and if no motion of the pressure gauge ensues T_t must be very nearly the equivalent temperature of the sky. If motion does ensue readjust the temperature T_t until the required condition is attained. Repeating the process with B in the place of A is a useful check on the accuracy of the determination. Provided T_t lies above the freezing point this is the most convenient method of observation, but T_t often lies far below the freezing point and to meet this case the following method is used :

To take an indirect observation :

A small metal cistern blacked with lamp smoke at the bottom and of triangular cross section is made to slide longitudinally over A and B with the bottom some 3 inches above the opening in the shield. This is filled

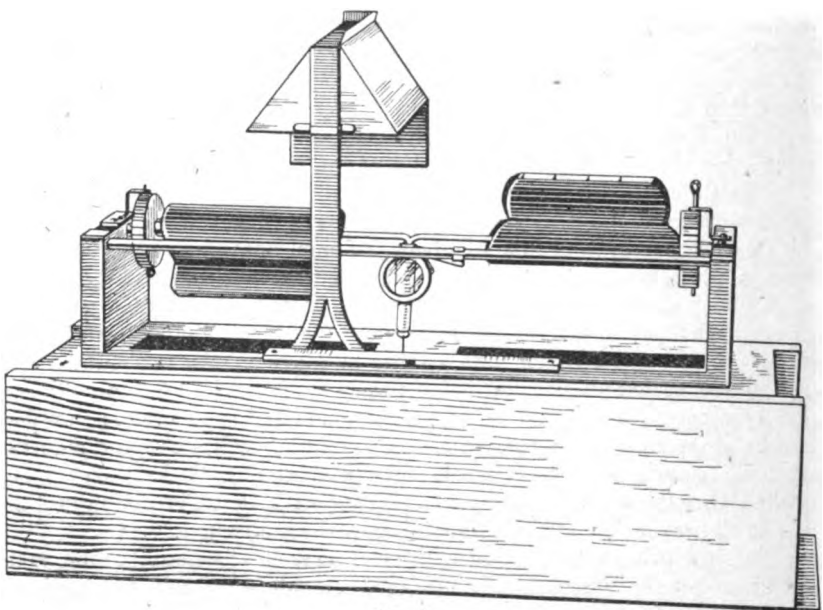

FIG. 1.

with warm water at temperature T_w. The warm water being above the thermometer bulb is without disturbing convective effect. Obviously it must be possible to place the cistern so that radiation from it and from the sky may just balance the radiation from the trough of water at T_t. For reasons given subsequently the temperature T_w is chosen so that the cistern at T_w may block out approximately half the solid angle of radiation issuing from the test tube A or B. Equilibrium is attained as before by adjustment until shifting the direction of the slit from the combined sky and cistern to the trough causes no change in the motion of the pressure gauge. Absolute stability of the gauge is not required ; the only condition is that the rate of change shall be unaltered. As before a check observation using B instead of A is useful.

The direct observation is probably the more accurate, but the indirect method has the advantage that radiation on the test tubes does not alter their temperature by any appreciable amount from that of the

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surrounding air. It also avoids the trouble and expense of cooling agents such as ether and liquid carbonic acid and can be used by any reasonably careful observer, who requires only two thermometers and a jug of warm water. Hence, save for experimental purposes, I use the indirect method only.

Calculation of the Equivalent Radiative Temperature.

Let T_s be the equivalent temperature of the sky, T_w that of the warm cistern, and T_t that of the water in the trough. Also let w be the solid angle of the cone of radiation from either test tube, and of this let $1-h$ of half of it fall upon the cistern, and the remainder, which is $1+h$ of half of it, fall upon the sky. Thus h is a small fraction and is zero when the cistern intercepts just half the radiation. The radiation from a 'black' body varies as the fourth power of the absolute temperature, and the adjustment has been made so that the combined radiation from the sky and the hot body shall equal the radiation from the trough. That is

$$\frac{1+h}{2}T_s^4 + \frac{1-h}{2}T_w^4 = T_t^4. \quad . \quad . \quad . \quad . \quad . \quad \text{I.}$$

Let $T_w - T_t = a$ and $m = \frac{a}{T_t}$.

Then $T_s^4(1+h) = 2T_t^4 - (a+T_t)^4(1-h) = T_t^4\{2-(1+m)^4(1-h)\}$

$$= T_t^4\{1+h-4m+4mh-6m^2+6m^2h-4m^3+\ldots\},$$

neglecting higher powers of m and h.

Hence $T_s = T_t\{1+h-4m+4mh-6m^2+6m^2h-4m^3+\ldots\}^{\frac{1}{4}} \times (1+h)^{-\frac{1}{4}}$,

and expanding and collecting the terms to the same order

$$T_t - T_s = a\{1-2h+3m-9mh+2h^2+9m^2\} \quad . \quad . \quad \text{II.}$$

Now m may reach as high a value as $1/8$, and, moreover, going to the next order, the coefficient of m^3 is found to be 18, hence formula II. is not accurate enough unless a and consequently m is small. But if m and h are small so that the second order terms in II. may be neglected the formula is very convenient for $3am$ may be written $3a^2/T_t$, and since T_t is not very far from 300 this becomes $T_t - T_s = a - 2ha + \cdot 01a^2$.

If a exceeds about 15° C. another method must be sought.

Equation I. may be written

$$(1-h)(T_w^4 - T_t^4) = (1+h)(T_t^4 - T_s^4),$$

or $$T_t^4 - T_s^4 = \frac{1-h}{1+h}(T_w^4 - T_t^4) = (T_w^4 - T_t^4)\{1-2h+2h^2-2h^3+\ldots\} \text{ III.}$$

To obtain T_s from this the values of T_w^4 and T_t^4 are taken from a table, their difference is multiplied by $(1-h)/(1+h)$, and this gives $T_t^4 - T_s^4$, whence with reference again to the table T_s is found.

The scale which indicates the position of the warm water cistern is naturally made first in terms of h, but it is more convenient that the scale reading should denote $(1-h)/(1+h)$ directly. The distance that the cistern must be moved from its central position to uncover 1/20 more ($h = 1/10$) of the total radiation passing through the slit in the shield is calculated as accurately as possible from the known size and shape of the instrument. Let this be x inches. The central position, *i.e.* half the solid angle covered, is marked 1·0 on the scale, and the distances for the

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marks for 0·9, 1·1, . . . etc., are required. Let the scale reading be $1 + n$, then

$$1 + n = \frac{1+h}{1-h}$$

$$\therefore h = \frac{n}{2+n} = \frac{n}{2}\left(1 + \frac{n}{2}\right)^{-1} = \frac{n}{2} - \left(\frac{n}{2}\right)^2 + \left(\frac{n}{2}\right)^3 - \ldots$$

and giving to n the values 1/10, 2/10, . . . etc., the scale can be set out. The scale should not go beyond the range 0·5 to 1·5.

Instead of a table giving T_t^4 simply it is better to multiply by Stefan's constant so that the radiation may be expressed in gramme calories per day or any other convenient unit. The tables are then useful for other purposes. The value of the constant used in framing the tables is that given in the Meteorological Office *Glossary*.

The difficulty about this process is to determine x. If the test tubes were of great length x would be 1/20 of the length, and if the test tube might be looked upon as a point the cone of radiation would be a right circular cone and x could be calculated. The actual case is a combination of the two. Diaphragms may be inserted in the shield to prevent all radiation that is not approximately perpendicular to the axis of the test tube and then the equivalent length of the test tube can be estimated. No serious error ensues so long as h is small, but it is obviously desirable to keep h small, which can be done by choosing T_w suitably. Using for the trough, T_t, the coldest water obtainable at the time of year without artificial cooling, for clear nights T_w ranges from about 80° to 100° F. as convenient values.

Probable Error of an Observation.

The conditions of working differ so greatly with the weather that it is hard to determine the probable error. In a room the temperature of a black radiating body can be determined by the instrument within 1 to 2° F. In the open, observations can be taken in a sheltered place unless the force of the wind exceeds 5 on the Beaufort scale, but naturally the accuracy is not so great as on a calm day. An observation takes 2 to 3 minutes, and consecutive observations, though taken with different test tubes and different values of T_w, on most nights show good agreement. The passage of a cloud or group of clouds greatly alters the radiation, and since the radiation is different on nights that to the eye are equally clear it follows that water vapour must play an important part. On some nights consecutive observations show much discordance, and since it is not known how much of this is real and how much instrumental it is difficult to estimate the probable instrumental error. I should put it at about 10 gramme calories per day. On clear nights the net radiation from the earth to the sky is at about the rate of 200 g.c. per day.

Character of the Radiation.

The test tubes can be blackened or left clean. It seems to make no difference at night which course is followed, but in the day with a clear sky the blackened tube shows the sky as warmer than the air, the unblackened tube as colder. No doubt this is because the plain glass is

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pervious to the scattered short-wave radiation from the sun while the blackened tube intercepts it.

Radiation at various Zenith Distances.

The cone of radiation from the instrument is roughly that of a pyramid on a square base, but close to the instrument a section will be rectangular. The vertical angle of the cone is about 45°. So large an angle is necessary to obtain sufficient sensibility, but it renders the determination of the radiation at precise zenith distances impossible.

TABLE I.—Full Radiation in Gramme Calories per Day per cm.^{2} at various Temperatures.

Temperature.	Absolute Scale.									
	0°.	1°.	2°.	3°.	4°.	5°.	6°.	7°.	8°.	9°.
°										
100	11	12	12	13	13	14	14	15	15	16
110	16	17	17	18	19	19	20	21	21	22
120	23	24	25	25	26	27	28	29	30	31
130	32	33	34	35	36	37	38	39	40	42
140	43	44	45	46	48	49	50	52	53	55
150	56	58	59	61	62	64	65	67	69	71
160	73	74	76	78	80	82	84	86	88	90
170	93	95	97	99	102	104	106	109	111	114
180	116	119	122	124	127	130	133	136	139	142
190	145	148	151	154	157	160	164	167	170	174
200	177	181	185	188	192	196	200	204	208	212
210	216	220	224	228	233	237	241	246	250	255
220	260	264	269	274	279	284	289	294	300	305
230	310	316	321	327	332	338	344	350	356	362
240	368	374	380	387	393	400	406	413	419	426
250	433	440	447	454	462	469	476	484	491	499
260	507	515	523	531	539	547	555	564	572	581
270	589	598	607	616	625	634	644	653	662	672
280	681	691	701	711	721	731	742	752	763	773
290	784	795	806	817	828	840	851	863	874	886
300	898	910	922	935	947	960	972	985	998	1011
310	1024	1037	1051	1064	1078	1092	1106	1120	1134	1148

Defining the zenith distance as the angle between the axis of the cone and the vertical, the net radiation as determined by the instrument from the earth to the sky seems to vary approximately as the elevation. It follows that radiation from the hemisphere of the sky to a horizontal plane will give as an average the value of radiation from the sky at an angle of 45°, so that to obtain the whole radiation from the sky observations should be made at an angle of 45°. Further investigations on this point are being made.

Actual Values of the Equivalent Temperature.

Observations have been taken intermittently since September 1919 on the zenith sky giving equivalent radiative temperatures ranging from 180° to 280°*a*. The low temperatures were confined to the winter months, chiefly, I believe, because the lower temperature of the air in

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winter ensures a lower water content of the atmosphere and therefore freer radiation outwards. The difference in radiative temperature from summer to winter is certainly much greater than the difference in the actual air temperatures, which is about 10° C. On nights that are heavily clouded the sky temperature differs but little from that of the surface air, as might be expected. Wind appears to make no difference to the radiation, though, of course, wind prevents the rapid cooling at sunset which would otherwise occur. On clear cold nights the net radiation from the earth may proceed at the rate of 250 g.c. per day, but the average rate for a clear sky is perhaps about 150 g.c.

TABLE II.—Full Radiation in Gramme Calories per Day per cm.^{2} at various Temperatures.

Temperature.	Fahrenheit Scale.									
	0°.	1°.	2°.	3°.	4°.	5°.	6°.	7°.	8°.	9°.
°										
−100	176	178	180	182	184	186	188	190	192	194
− 90	196	199	201	203	205	208	210	212	214	217
− 80	219	221	224	226	228	231	233	235	238	240
− 70	243	245	248	250	253	256	258	261	264	266
− 60	269	272	274	277	280	283	286	288	291	294
− 50	297	300	303	306	309	312	315	318	321	324
− 40	327	330	333	336	339	342	346	349	352	356
− 30	359	362	366	369	373	376	380	383	387	390
− 20	394	398	401	405	408	412	416	419	423	427
− 10	431	435	439	442	446	450	454	458	462	466
0	470	475	479	483	487	491	496	500	504	509
10	513	517	522	526	531	535	540	544	549	553
20	558	562	567	572	577	582	586	591	596	601
30	606	611	616	621	626	631	636	642	647	652
40	657	662	668	673	678	684	689	695	700	706
50	711	717	723	728	734	740	746	751	757	763
60	769	775	781	787	793	799	805	811	817	824
70	830	836	842	849	855	861	868	874	881	888
80	894	901	907	914	921	928	935	941	948	955
90	962	969	976	984	991	998	1005	1013	1020	1027
100	1035	1042	1049	1057	1064	1072	1079	1087	1095	1102

Note.—In the negative part of the scale the numbers at the head of the columns are inverted. Thus in the − 10 row and the 2° column the number 439 refers to the temperature of − 10° + 2°, that is, to − 8° F. not to − 12° F.

It is hoped to follow up this enquiry by the use of the instrument, as there are many interesting points that require elucidation.

The illustration shows the general design of the instrument, as used at Benson.

The two tables give the full radiation in gramme calories per day from one square centimetre of surface at various temperatures, and are added for reference. (From one side only.)

Note added June 16, 1920.—Experience has shown that the blacking with soot of the bottom of the warm water cistern does not make it a full radiator, but the shape can be altered to attain that end.

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Radiation at various Zenith Distances.

This varies considerably with the type and amount of cloud, but for clear nights it has been found that the radiation in a small solid angle falling perpendicularly on the receiving surface is not much altered from that found in the zenith till a zenith distance of 30° or 40° is passed. If 100 denotes the net radiation to the zenith, and 0 be the value to the horizon, the following are approximate values found in the last fortnight of May for clear nights.

Altitude	90°	75°	60°	45°	30°	15°	0°
Radiation	100	99	96	89	73	43	0

Values of the Equivalent Temperature.

For the present time of year (June) the equivalent temperature of the sky near the zenith seems to be about 15° F. on clear nights. I hope to be able to carry out a regular set of observations so as to get rough mean values for the different seasons; for the winter it is perhaps about − 20° F.

DISCUSSION.

Lt.-Col. E. Gold said that Mr. Dines was to be congratulated on the way in which he had tackled a very difficult problem. Measurements of radiation outwards had been attempted a good many times by physicists and meteorologists, but, so far as he knew, no one had overcome the intrinsic difficulties of the experiment. In Mr. Dines's direct method of observation there were, so far as he could see, no appreciable sources of error either from convection, or radiation from other surfaces, that could affect the value of the observations obtained; and he hoped it would be possible to get from the instrument a series of accurate observations of the radiation downwards of the atmosphere. It was important in considering the paper to understand what was meant by the "equivalent radiative temperature" of the sky. It was merely the solution of an equation in which σT^4 equals the sum of the downward radiation from the atmosphere. The downward radiation would be different in different wave-lengths, and it was extremely improbable that the distribution in wave-lengths would be the same as the distribution in the radiation from a black body at temperature T. In the course of the paper Mr. Dines said that the net outward radiation from the earth was about 200 g.c. per day; in another part he expressed the view that it varied between 150 and 250 g.c. per day; and in still another part he gave the equivalent temperature of the sky, that is T_s, as varying from 180 to 280 a., 280 being the temperature on cloudy nights. Taking 180 and using Mr. Dines's table it would be found that the downward radiation would be 120 g.c., and taking the earth as having had a temperature of 270 a., the outward radiation came to 590 g.c. The difference would be 470, and that 470 was to be compared with the 250 calculated in another part of the paper. There should be some way of reconciling these values, though he could not see how it could be done. It might be that Mr. Dines had used equivalent radiative temperature merely for the zenith and had computed radiation for the whole hemisphere, and that the discrepancies had occurred in that way. If the equivalent temperature was correct the outward radiation ought to be at the rate of 400 to 500 g.c. per day, even in winter.

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The values had another interest because they ought to help in obtaining some idea as to the spectral distribution of radiation in the atmosphere. Some years ago he had computed what the downward radiation in the atmosphere would be (using the information that was then available) on two assumptions: the first, that 25 per cent went through the atmosphere without being affected in any way; the second, that it was all affected in some way and that any absorption or diffusion was spread throughout the spectrum. He had got very different results in the two cases—in the first case the downward radiation coming out at about half, in the second case at about 95 per cent, of the radiation from the earth. From what he could see from Mr. Dines's results the truth lay somewhere between the two assumptions. He hoped Mr. Dines's results would also find application in practical everyday forecasting. It was not too much to hope that it would be possible to compute beforehand with a good deal of accuracy what the warming-up effect of the radiation coming from the sun and the radiation going out from the atmosphere at the same time would be in the course of several days on air moving slowly. Already it was known that the sun's radiation would suffice to raise the temperature of a layer of air 1000 m. (3300 feet) thick about 10° F. in the course of a day in June if 60 per cent of it were transmitted through the atmosphere; but it was not known how much the same layer would lose by radiation at night.

Mr. W. W. BRYANT asked whether there would not be radiation from the sky reflected into the instrument from the cover in certain positions.

Mr. J. S. DINES said that he would leave Col. Gold's remarks to be replied to by Mr. W. H. Dines. In reply to Mr. Bryant he pointed out that the shield round the test tube was blackened inside, so that radiation reflected from the side of the water cistern would not affect the readings.

Sir NAPIER SHAW said that the Society was very glad to accept a contribution from Mr. Dines on the important subject of radiation. Apart from the value of the actual readings of the instrument, the mere watching of the changes that the instrument indicated as clouds and other conditions of the sky passed over the place of observation would be in itself material for an interesting contribution to our knowledge of what was taking place in the atmosphere. Not all clouds showed themselves as water drops; the variation in the apparent temperature of the sky would be a guide to invisible conditions.

Mr. W. H. DINES in reply wrote that Col. Gold was right in his surmise, and that the equivalent temperatures given referred to the zenith and not to the whole hemisphere. The 200 g.c. per day net radiation referred to the general average for clear weather and to the whole hemisphere; the low value of 180 a. for the equivalent temperature was on an exceptional night in winter and referred to the zenith. Still the difference was too large, and it remained for observations in the next winter to settle whether the value of 180 a. was within the ordinary winter range or had been due to an instrumental error. The matter was important because if such low values of the back radiation from the zenith sky were genuine it showed that the constant of radiation for dry air was much lower than had been supposed. In reply to Sir Napier Shaw he thought that the effect of clouds was very apparent, but that it was not easy to identify any particular cloud with the change of radiation.

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REPORT ON THE PHENOLOGICAL OBSERVATIONS IN THE BRITISH ISLANDS, FROM DECEMBER 1918 TO NOVEMBER 1919.

No. 29, New Series.

By J. EDMUND CLARK, B.A., B.Sc., F.G.S., and HENRY B. ADAMES, F.R.A.S.

[Communicated May 19, 1920.]

War-time attrition has further reduced observers to 103, but we are glad to report a reasonable expectation that this very low number will be more than doubled in 1920, which completes the 30 years of the present series.

Unless otherwise stated, mean values are for the 25 years 1891 to 1915. The numbers represent days elapsed from New Year, midnight. Hence −31 is December 1st, 32 is February 1st, and so on.

Weather Summary.

Printing exigencies require yet more compression, so that we must largely leave our tables to speak for themselves, giving only the barest outline, and for details of agricultural and horticultural conditions refer to reports elsewhere. A *rainfall* excess in England was rather more than outweighed by deficiency elsewhere, the excess due to the totals from December to April, often from snow, culminating in a heavy fall on April 27. December 1919 also was wet, but nearly all parts had continuous shortage in the intervening months, May, June and in some parts October giving serious droughts. *Sunshine* differed little from the normal. *Temperature* was marked by extreme cold in March and still more in November. The cold of late June and all July seriously checked summer growth, accentuating the delays from the previous drought. The later months favoured the apple crop, which was finer in quality and colouring than most people could remember. The autumn tints, likewise, were of a splendour rarely seen here.

The tables show that the four early spring flowers were nine days late, the difference then lessening until from the genial May weather the ox-eye daisy was early by a day. The other four summer flowers were four to seven days early in England and Wales, and the autumn flowering ivy ten days. The remarkably warm December (1918) naturally gave an early date for the thrush, but the early migrants, swallow, cuckoo and nightingale, were decidedly late, especially the last. Insect dates are even more belated for the bee, wasp and white butterfly.

OBSERVERS' NOTES

have again been carefully digested, but only the briefest summaries are possible.

The Observing Form has been reconstructed. The migrant list is placed on the same sheet as the records for our three chief tables, and there is a supplement of four additional flowers which inform us about the earlier months. The large black and red humble bee is also added, since the honey

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TABLE I.—Variations from the Average in Temperature, Rainfall, and Sunshine, 1918–19.

Daily Temperature.

Months.	Eng. S.W.	Ire. S.	Eng. S.E.	Eng. Mid.	Eng. E.	Eng. N.W.	Ire. N.	Scot. W.	Eng. N.E.	Scot. E.	Scot. N.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
December .	+4·0	+3·2	+4·9	+5·0	+4·7	+4·0	+3·6	+2·0	+3·2	+1·6	+1·3
January .	−1·3	−1·6	−0·7	−1·1	−0·7	−1·1	−1·1	−0·9	−1·3	−1·4	−1·3
February .	−3·4	−1·4	−3·1	−4·5	−3·6	−3·4	−2·0	−3·2	−3·1	−4·3	−4·1
Winter .	−0·2	+0·1	+0·4	−0·2	+0·1	−0·2	+0·2	−0·7	−0·4	−1·4	−1·4
March .	−2·2	−3·1	−1·4	−2·8	−2·2	−3·4	−3·4	−3·4	−2·9	−4·3	−3·2
April .	−1·4	0·0	−1·3	−0·5	−0·9	−0·5	−0·2	−0·2	+0·5	0·0	−0·5
May . .	+3·1	+2·9	+3·6	+4·9	+3·4	+5·0	+3·4	+4·5	+3·8	+3·2	+3·6
Spring .	−0·2	−0·1	+0·3	+0·5	+0·1	+0·4	−0·1	+0·3	+0·5	−0·4	0·0
June . .	0·0	−0·2	+0·3	+1·1	+0·7	+0·2	−1·1	−0·9	+1·8	+0·2	−0·4
July . .	−1·4	−0·5	−3·4	−2·2	−4·0	−1·8	−1·3	−1·1	−2·5	−1·8	−0·7
August .	+2·0	+2·2	+1·8	+2·0	+1·4	+0·4	+0·5	+0·2	+1·3	+0·4	−0·5
Summer .	+0·2	+0·5	−0·4	+0·3	−0·6	−0·4	−0·6	−0·6	+0·2	−0·4	−0·5
September.	−0·4	−0·4	0·0	−0·2	+0·4	−0·2	−0·5	−0·7	+0·4	−0·5	−0·5
October .	−2·9	0·0	−4·1	−3·2	−4·0	−2·2	+0·4	−0·7	−2·7	−0·9	−0·7
November.	−5·9	−5·9	−5·8	−5·0	−5·6	−5·2	−4·9	−5·8	−5·6	−6·5	−5·6
Autumn .	−3·1	−2·1	−3·3	−2·8	−3·1	−2·5	−1·7	−2·4	−2·6	−2·6	−2·3
Year. Dec.–Nov.	−0·8	−0·4	−0·8	−0·6	−0·9	−0·7	−0·6	−0·9	−0·6	−1·2	−1·1

\+ indicates above the average, − below it.

Total Rainfall.

[25 millimetres practically equal 1 inch; hence 0·04 inch equals 1 mm.]

	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
December .	+21	+30	−18	+14	+14	+51	+18	+25	+22	−14	−14
January .	+50	+24	+57	+34	+30	+14	+19	+8	+36	+22	−50
February .	+23	−19	+11	+16	+26	−36	−43	−72	+13	−15	−86
Winter .	+94	+35	+50	+64	+70	+29	−6	−39	+71	−7	−150
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
March .	+57	−6	+48	+63	+12	+55	+3	+13	+21	−6	−16
April .	−1	−26	+20	+4	+19	−6	−13	−1	+2	+18	+55
May . .	−31	+14	−34	−32	−31	−26	−2	−42	−31	−33	−45
Spring .	+25	−18	+34	+35	0	+23	−12	−30	−8	−21	−6

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TABLE I.—VARIATIONS FROM THE AVERAGE—*continued.*

Total Rainfall—continued.

MONTHS.	Eng. S.W.	Ire. S.	Eng. S.E.	Eng. Mid.	Eng. E.	Eng. N.W.	Ire. N.	Scot. W.	Eng. N.E.	Scot. E.	Scot. N.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
June .	−27	−12	−26	−29	−16	−18	+20	+39	−26	−5	+43
July .	−33	−38	−1	+6	+7	−40	−48	−55	−10	−52	−50
August .	−4	−21	+2	−2	+4	−5	−14	−16	−1	−26	+10
Summer .	−64	−71	−25	−25	−5	−63	−42	−32	−37	−83	+3
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
September.	−22	−9	−18	−7	−28	−7	+5	+12	−7	+9	+54
October .	−63	−69	−64	−15	−18	−29	−49	−68	+16	−15	−42
November.	−28	−44	−14	−22	−7	−35	−17	−30	+14	+48	+2
Autumn .	−113	−122	−96	−44	−53	−71	−61	−86	+23	+42	+14
YEAR.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Dec.–Nov.	−58	−176	−37	+30	+12	−82	−121	−187	+49	−69	−139

Daily Sunshine.

	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
December .	−0·08	+0·29	−0·36	−0·13	−0·30	−0·13	+0·30	+0·11	−0·06	+0·22	+0·23
January .	+0·33	+0·42	−0·41	−0·13	−0·64	+0·09	+0·36	+0·12	−0·14	−0·10	+0·23
February .	−0·16	−0·03	−0·62	−0·54	−0·69	−0·08	+0·77	−0·04	−0·70	−0·43	+0·24
Winter .	+0·03	+0·23	−0·46	−0·27	−0·54	−0·04	+0·48	+0·06	−0·30	−0·10	+0·23
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
March .	0·00	−0·46	−0·92	−0·36	−0·90	−0·45	−0·17	+0·12	−0·98	−0·01	+0·86
April .	−0·20	+0·08	−1·13	−1·07	−1·46	−0·95	+0·13	−0·70	−1·07	−1·16	−0·73
May .	−0·26	−1·14	+1·34	+1·23	+2·13	+1·09	+0·15	+0·23	+1·41	+0·63	+0·87
Spring .	−0·15	−0·51	−0·24	−0·07	−0·08	−0·10	−0·04	−0·12	−0·21	−0·18	+0·33
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
June .	+0·16	−0·30	+0·15	+0·47	+0·60	+0·06	−0·55	+0·03	−0·31	−0·13	−0·84
July .	+0·49	+0·62	−2·97	−1·68	−2·77	−0·42	+0·43	+1·71	−1·71	+1·11	−0·71
August .	+0·74	+1·00	+1·22	+0·97	+0·83	+0·09	+0·65	+0·95	+0·68	+1·03	+0·15
Summer .	+0·46	+0·44	−0·53	−0·08	−0·45	−0·09	+0·18	+0·90	−0·45	+0·67	−0·47
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
September.	−0·05	+0·53	+0·26	+0·16	+0·47	+0·42	+0·50	+0·30	+0·22	+0·89	+0·35
October .	+1·40	+0·61	+1·37	+1·47	+0·96	+0·78	+0·40	+0·82	+0·98	+0·05	0·00
November.	−0·03	+0·54	−0·46	−0·54	−0·36	−0·19	+0·45	+0·16	−0·27	+0·24	+0·05
Autumn .	+0·44	+0·56	+0·39	+0·36	+0·36	+0·34	+0·45	+0·43	+0·31	+0·39	+0·13
YEAR.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
Dec.–Nov.	+0·20	+0·18	−0·21	−0·02	−0·18	+0·03	+0·27	+0·32	−0·16	+0·20	+0·06

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TABLE II.—List of the Stations furnishing Plant, Insect, and Bird Records, with the Names of the Observers.

(*, Plant records only; †, Bird and Insect records only.)

Station.	County.	Height above Sea-level.	Observer.
		Ft.	
A			
1. Falmouth	Cornwall	80	Commander A. Rogers, R.N.R.
2. Duloe	Cornwall	480	C. S. Hooper.
2a* Polperro	Cornwall	...	Miss H. M. M. Perrycoste.
3. Tiverton	Devon	270	Miss M. E. Gill.
4. Wellington	Somerset	220	W. P. Martin, Jun., M.A.
5. Street	Somerset	60	E. A. Litten and H. Underwood.
6. Winscombe (Crooks Peak)	Somerset	110	W. H. Stephens.
7. Weymouth	Dorset	100	N. M. Richardson.
8. Ansty, Dorchester	Dorset	470	Miss E. E. Woodhouse.
9. Pulham	Dorset	350	Rev. J. Ridley.
10. Edmondsham	Dorset	100	Rev. E. F. Linton, F.L.S.
11. Verwood	Dorset	150	J. H. Salter, D.Sc.
12. Bridgend	Glamorgan	60	H. J. Randall.
13. Hafod, Aberystwyth	Cardigan	580	D. H. Dunn. F.R.H.S.
B			
1. Ferns	Wexford	260	C. E. J. Greene, M.A., D.Sc.
2. Vale of Clara, Rathdrum.	Wicklow	300	Miss L. T. McCausland.
3. Mountmellick	Queen's County	250	Mrs. Pim.
C			
1† Bournemouth	Hants	...	Frank Penrose.
1a† Lymington	Hants	...	P. A. Ourry.
2. Beaulieu	Hants	100	Mrs. M. A. Nash-Brown.
3. Marlborough	Wilts	440	J. C. Alsop.
4. Botley	Hants	40	Lady M. S. Jenkyns.
5. Bembridge	Isle of Wight	80	C. Orchard, F.R.H.S.
6. Petersfield	Hants	420	G. Abbey.
7. Havant	Hants	40	H. Beeston, M.B.O.U., M.C.S.
8. Chichester	Sussex	250	Miss B. Farley.
9. Fleet	Hants	275	Miss M. L. Hodgson.
10. Farnham	Surrey	400	Mrs. H. M. Gohery.
11. Hove	Sussex	200	E. J. B. Sopp, F.E.S.
12. Cuckfield	Sussex	...	C. F. Wood.
13. Lower Beeding, Horsham	Sussex	300	Miss E. M. Godman.
14. Cranleigh	Surrey	180	Miss H. E. Ravenscroft.
15. Purley	Surrey	350	J. E. Clark, B.A., B.Sc., F.R.Met.Soc., and friends.
16. Hellingly	Sussex	170	Mrs. M. Stroud.
17. Maidstone	Kent	100	H. J. Elgar.
D			
1. Oxford	Oxford	210	F. A. Bellamy, M.A., F.R.A.S.
2. Weston Turville	Bucks	320	G. E. Eland.
3. Ross	Hereford	210	Miss M. L. Southall.
4. Dymock	Gloucester	120	Miss M. Peake.
5. West Malvern	Worcester	600	Mrs. E. Kensington.
6. Ashorne	Warwick	160	G. T. Osborn, F.R.Met.Soc.
7. Farnborough	Warwick	520	Miss C. A. Prater, A.R.R.C.

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TABLE II.—List of the Stations with the Names of Observers—*continued.*

Station.	County.	Height above Sea-level.	Observer.
		Ft.	
8. Northampton	Northampton	320	H. N. Dixon, M.A., F.L.S.
9. Staunton-on-Arrow	Hereford	400	Rev. S. Cornish Watkins.
10. Bromyard (Saltmarshe Castle)	Hereford	520	S. Horton.
11. Tenbury	Worcester	310	Fredk. Lowe.
12. Wolverley (Cookley)	Worcester	...	T. J. Beeston.
13. Quinton, Birmingham	Warwick	...	W. Haycock.
14. Kibworth	Leicester	210	Miss M. E. Whitton.
15. Glaston, Uppingham	Rutland	400	The Very Reverend W. G. Whittingham, Archdeacon of Oakham.
16. Edgmond, Newport	Shropshire	220	A. Roebuck.
17. Hodsock	Notts	60	Miss A. Mellish, F.R.H.S.
18. Sitwell Vale, Rotherham	Yorks (W.R.)	300	G. Howard.
19. Goole	Yorks (W.R.)	10	J. Harrison.
20. Kirkheaton	Yorks (W.R.)	250	E. Fisher.
21. Middlestown	Yorks (W.R.)	420	J. Hooper.
22† Hebden Bridge	Yorks (W.R.)	330	Walter Greaves.
23. Altofts	Yorks (W.R.)	120	H. G. Townsend.
24. Tadcaster (Steeton Hall)	Yorks (W.R.)	50	W. G. Bramley.
25† Wilsden, Bradford	Yorks (W.R.)	600	E. P. Butterfield.
26. Cross Hills, Keighley	Yorks (W.R.)	350	J. Holmes.
27. Menston-in-Wharfedale	Yorks (W.R.)	400	Miss W. M. Wheatley.
E			
1. Watford	Herts	270	Mrs. J. Hopkinson, F.R.H.S.
2. Berkhamsted	Herts	400	Mrs. E. Mawley.
3. Bennington	Herts	400	Miss E. A. Parker, F.R.Met.Soc.
4. Letchworth	Herts	320	W. P. Westell, F.L.S., M.S.P.
5. Lexden	Essex	90	S. F. Hurnard.
6. Cambridge	Cambridge	40	L. Doncaster, Sc.D.
6a. Bungay	Suffolk	120	H. B. Dobbie.
7. Hapton	Norfolk	...	Miss E. J. Barrow.
8. Norwich	Norfolk	100	A. W. Preston, F.R.Met.Soc.
9. King's Lynn	Norfolk	..	A. Hitchcock.
10. Hevingham (Rippon Hall)	Norfolk	90	Major H. S. Marsham.
11. Stalham (Brunstead)	Norfolk	30	Rev. M. C. H. Bird.
F			
1. Higher Tranmere, Birkenhead	Cheshire	100	Mrs. F. B. Dallman.
2. Scarisbrick, Ormskirk	Lancashire	70	Mrs. J. Johnson.
3. Southport	Lancashire	20	C. Rhodes.
4. Leyland	Lancashire	130	H. Nowell ffarington
5. Urswick, Ulverston	Lancashire	150	J. Dobson.
6† Ulverston	Lancashire	300	H. B. Turney.
7. Ambleside	Westmorland	220	Miss A. C. Drury.
8† Ambleside	Westmorland	...	A. Astley.

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TABLE II.—List of the Stations with the Names of Observers—*continued.*

Station.	County.	Height above Sea-level.	Observer.
		Ft.	
G			
1. Rostrevor	Down	1000	Convent of Mercy pupils.
2. Enniskillen	Fermanagh	200	J. P. Burkitt.
3. Belfast	Down	...	T. McCloy.
4* Bangor	Down	70	E. G. Ingold.
5. Westport	Mayo	20	...
5a. Magherafelt	Londonderry	200	Sister M. Borromeo Corbett.
6. Altnafoyle	Londonderry	400	T. Gibson.
H			
1. Kirkmaiden	Wigtown	200	Rev. D. R. Williamson.
2. Moniaive	Dumfries	350	J. Corrie.
3. Milngavie	Dumbarton	150	Major R. M. Ker, F.R.Met.Soc.
I			
1. Belton, Grantham	Lincoln	150	Miss F. H. Woolward.
2. Thirsk	Yorks (N.R.)	120	A. B. Hall.
3. Scarborough	Yorks (N.R.)	90	A. J. Burnley.
4. Corbridge-on-Tyne	Northumberland	200	A. W. Price.
J			
1. Broughton	Peebles	600	R. J. Hogg.
2† Broughton	Peebles	700	A. C. Gairns.
3. West Foulden	Berwick	250	J. H. Craw.
4. Kirkcaldy	Fife	...	N. M. Johnson, B.Sc., L.C.P.
5† Ellon	Aberdeen	40	J. Rae.
K			
1. Beauly	Inverness	50	A. Birnie.
2. Ardross Castle, Alness	Ross	450	W. F. Minty.

bee is so seriously affected by the Isle of Wight disease. But the migrants and extra flowers are *quite of secondary importance*[1] compared with the chief tables. Still the four flowers are so often given that it seems worth while to include them. We especially ask for suggested improvements in view of the second series of 30 years beginning with 1921.

Other Plant Records.—Mean dates: snowdrop (18 records), January 22; winter aconite (13), 7th; celandine (8), February 15; crocus (16), March 3. The fifty typical early spring garden flowers at Asgarth, Purley,[2] averaged February 9 against February 3 in 1918; March 22 in 1917; January 16 in 1913 [and February 1 in 1920].

Birds.—Several observers note recovery of numbers from the destruction in recent winters.

Insects.—In most parts garden whites and Vanessidæ were very infrequent. Bee disease continued serious. Six records of the humble bee averaged April 10.

Pests.—Oakwoods again suffered seriously in several parts. Green-fly

[1] We would like, however, to except the *swift*, so easy to identify and widespread.

[2] Full phenological notes appear in the Croydon *Nat. Hist. and Sci. Soc. Reports*: a few reprints are available per J. E. Clark.

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FIG. 1.—Phenological Districts and Stations, 1919. Also Weekly Floral Isophenes from 110 to 152 days.

110 = April 20. 117 = April 27. 124 = May 4. 131 = May 11.
138 = May 18. 145 = May 25. 152 = June 1.

Isophenes - - - - - - District Boundaries ————

The district letters and station numbers refer to Table II.
(Note again effect of high ground, *e.g.* Marlborough, Chilterns, Weald, Downs, Central Wales.)

[Station 5, District G (Ireland N.), is incorrectly shown, and should appear one degree south and one degree west of its position.]

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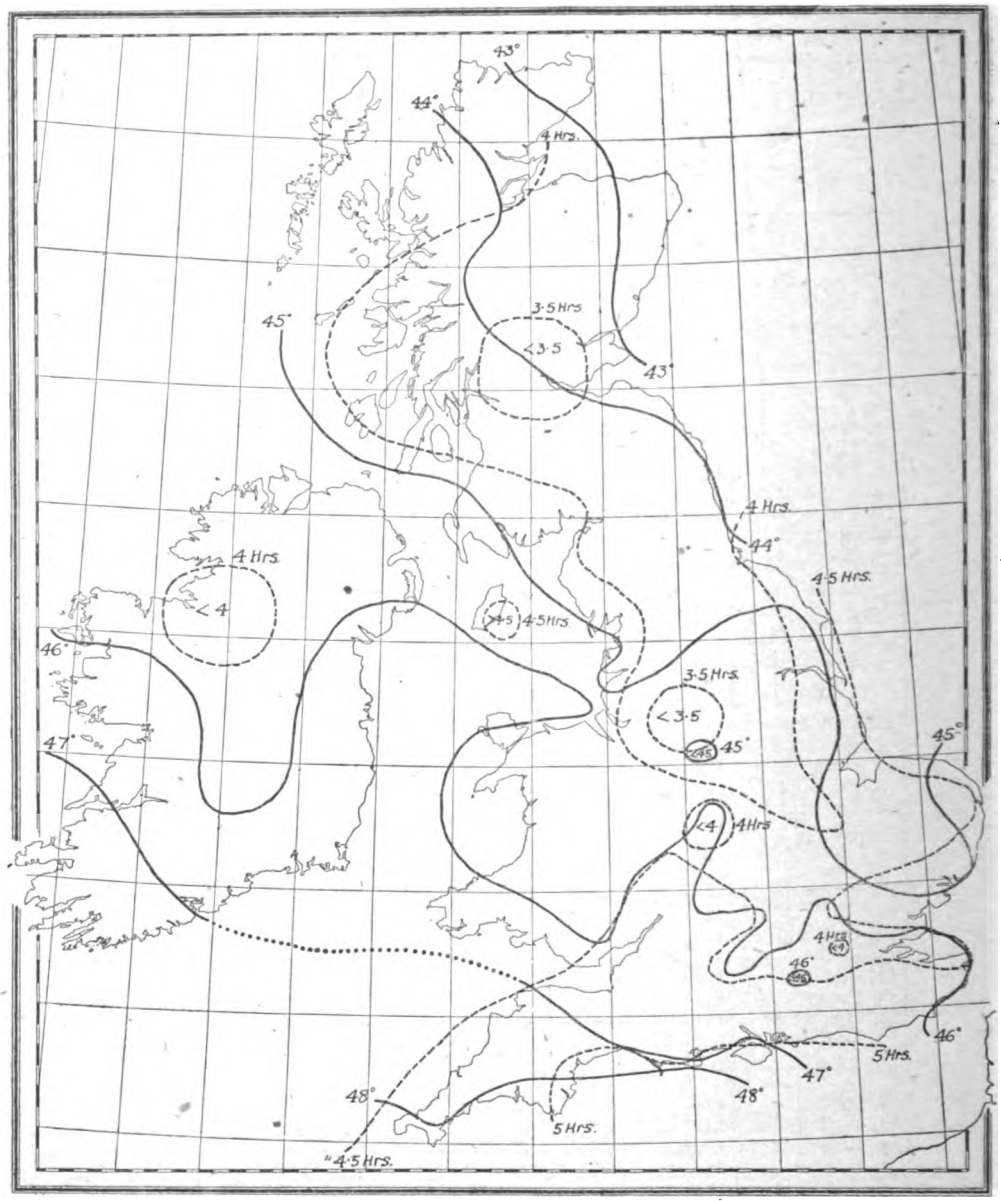

FIG. 2.—Isotherms, or lines of equal temperature, and Isohels, or lines of equal sunshine, during the six months January to June 1919.

Isotherms———— Isohels - - - - -

rarely gave much trouble, but the turnip and celery flies took advantage of the unfavourable summer weather conditions.

THE SPRING MIGRANT TABLE (No. VII.) is unfortunately less complete than in 1918. The mean date, April 27, is 2 days earlier and is the same as the six years' mean. The first seven species average 5½ days behind the *Nat.*

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TABLE III.—Date (Day of Year) of First Flowering of Plants, 1919.

Station.	Mean Value excluding Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.
A														
1. Falmouth	119	31	...	105	64	...	117	129	148	150	161	...	179	246
2. Duloe	111	44	47	71	73	85	117	120	132	153	...	...	...	...
2a. Polperro	...	...	...	*80	*60	*115	...	*133	...	*159	*163	...	...	*256
3. Tiverton	120	22	56	84	80	112	130	118	149	159	158	...	189	270
4. Wellington	...	...	67	...	...	104	...	...	...	...	...	...	186	...
5. Street	...	...	40	...	104	66	93	...	...	...	...	...	...	...
6. Winscombe	128	56	91	102	94	114	131	136	149	154	168	...	166	273
7. Weymouth	...	...	...	91	95	124	134	135	...	...	...	...	...	...
8. Ansty, Dor'r	123	28	67	76	99	107	130	129	137	153	162	196	190	250
9. Pulham	135	...	114	106	110	129	126	139	...	155	...	...	...	...
10. Edmonds'm	121	51	71	86	98	102	126	133	144	152	161	165	164	...
11. Verwood	115	18	15	75	79	121	128	136	138	156	159	181	176	...
12. Bridgend	132	53	69	...	119	127	134	142	151	162	165	...	178	...
13. Hafod, Ab'th	142	62	...	109	118	...	143	150	160	168	187	189	201	266
B														
1. Ferns	134	59	90	99	102	...	130	137	150	164	182	189	191	274
2. Vale of Clara	...	39	...	...	67	...	...	...	...	...	...	...	...	...
3. M'ntmellick	126	59	56	92	99	116	126	137	139	150	176	...	177	277
C														
2. Beaulieu	125	46	...	91	100	114	129	133	139	137	165	186	...	...
3. Marlborough	...	1	...	...	123	...	...	...	...	153	161	198	...	...
4 Botley	126	11	77	95	108	116	134	137	141	...	166	...	191	271
5. Bembridge	120	25	*15*	93	...	118	119	...	124	146	...	...	...	...
6. Petersfield	131	60	82	95	103	...	130	136	134	...	...	...	...	...
7. Havant	118	19	54	85	110	106	...	135	140	147	160	161	179	273
8. Chichester	128	59	85	81	82	118	124	131	148	152	164	208	178	251
9. Fleet	...	...	...	...	...	109	...	144	144	156	166	...	...	...
10. Farnham	128	55	65	82	112	120	131	131	142	152	...	...	...	...
11. Hove	127	...	75	...	119	120	128	138	140	152	165	173	168	252
12. Cuckfield	122	53	50	62	115	119	129	130	140	140	174	176	174	262
13. L. Beeding	123	28	67	76	99	118	135	...	...	151	...	...	...	...
14. Cranleigh	130	...	...	...	113	121	...	135	149	155	...	...	184	...
15. Purley	133	52	70	99	112	126	132	138	149	157	166	194	197	...
16. Hellingly	112	8	37	71	50	100	125	126	136	144	183	182	177	248
17. Maidstone	121	26	...	72	105	110	131	136	140	148	158	...	...	252
D														
1. Oxford	124	8	...	98	109	109	131	136	145	152	166	...	182	...
2. W. Turville	132	...	...	...	123	115	136	135	152	155	173	200	179	...
3. Ross	123	...	...	...	98	110	128	136	145	152	160	...	...	232
4. Dymock	134	57	76	101	112	114	133	142	...	...	...	...	194	256
5. W. Malvern	124	25	47	92	119	87	116	139	157	156	165	184	199	216
6. Ashorne	126	61	...	108	119	120	135	138	144	151	...	215	...	...
7. Farnborough	126	3	72	99	100	124	136	136	150	151	165	...	188	256
8. Nor'ampton	129	69	...	...	111	124	136	138	145	152	160	180	177	261
9. Staunton	125	13	73	85	105	114	129	137	152	149	159	193	185	254
10. Bromyard	...	10	...	66	...	...	...	...	...	...	...	...	...	...
11. Tenbury	131	56	84	100	112	119	132	139	147	151	165	202	168	254
12. Wolverley	135	56	74	...	120	137	126	139	...	150	...	...	...	273
13. Quinton, B'm	128	45	55	88	102	113	130	132	156	158	167	190	199	233
14. Kibworth	134	...	55	101	129	125	139	142	150	157	...	...	...	...

* Received too late for including in means.

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TABLE III.—Date (Day of Year) of First Flowering of Plants, 1919—*continued.*

Station.	Mean Value excluding Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.
15. Glaston	...	7	...	...	106	117	132	137	...	152	...	...	...	...
16. Edgm'd, New.	133	58	75	...	117	115	135	140	...	152	...	...	...	269
17. Hodsock	130	53	53	108	111	122	133	135	153	153	171	184	181	259
18. Sitwell Vale.	...	96	57	...	...	...	...	...	...	...	...	...	...	...
19. Goole	126	71	63	...	112	125	138	141	124	124	150	...	186	297
20. Kirkheaton	144	75	96	110	121	143	145	145	157	168	194	187	185	...
21. Middlestown	139	63	60	101	123	...	137	136	161	165	200	...	...	283
23. Altofts	132	54	53	...	...	...	138	144	156	165	166	186	188	...
24. Tadcaster	132	73	55	95	121	110	137	140	156	170	170	175	...	293
26. Crosshills	136	45	75	103	130	130	140	145	150	161	173	188	190	266
27. Menston	141	...	87	104	124	...	138	145	156	167	186	195	206	...
E														
1. Watford	131	60	...	...	109	108	133	136	147	151	190	192	...	245
2. Berkhamst'd.	134	59	85	110	121	123	134	137	147	156	178	191	170	277
3. Bennington	...	...	...	...	116	...	...	...	150	155	...	205	...	...
4. Letchworth	128	55	60	95	110	123	133	133	142	145	163	193	179	256
5. Lexden	121	36	61	101	76	109	128	131	141	152	162	176	174	...
6. Cambridge	122	10	61	...	...	124	133	136	146	150	157	...	170	...
6a. Bungay	133	23	40	84	100	120	145	140	155	170	218	201	205	280
7. Haptom	...	*35	...	...	113	...	...	...	...	...	...	...	...	...
8. Norwich	127	...	...	86	109	124	131	141	143	153	...	...	176	254
9. Kings Lynn	137	...	...	...	104	137	137	139	151	159	197	200	200	...
10. Hevingham	...	...	...	95	...	...	...	129	...	...	...	...	...	...
11. Stalham	137	50	...	...	...	...	138	142	156	161	185	...	197	...
F														
1. Birkenhead	129	18	55	99	114	111	131	135	149	175	184	182	...	252
2. Scarisbrick	...	*100*	80	...	...	126	127	139	143	...	...	...	...	...
3. Southport	...	...	83	...	...	...	136	138	...	...	...	...	...	...
4. Leyland	141	73	...	99	...	...	136	144	162	169	...	...	...	...
5. Urswick, Ulv.	132	42	62	93	120	...	143	144	151	152	202	163	182	256
7. Ambleside	129	48	64	90	118	126	133	142	148	151	184	165	184	263
G														
1. Rostrevor	131	58	...	101	81	...	135	121	...	154	...	...	222	...
2. Enniskillen	...	34	76	79	...	109	134	...	...	...	...	...	...	...
3. Belfast	...	...	*111*	111	...	*111	...	...	...	...	...	...	...	...
4. Bangor	133	40	72	...	109	...	135	135	†137	171	...	...	205	...
5. Westport	...	...	...	...	105	...	....	118	...	154	...	...	...	265
5a. Magherafelt	...	...	...	...	...	...	...	115	...	...	...	...	...	...
6. Altnafoyle	139	...	67	...	110	...	135	142	...	167	206	...	...	...
H														
1. Kirkmaiden	138	45	38	97	118	...	146	145	165	168	...	206	201	269
2. Moniaive	...	...	...	...	...	...	142	148	...	...	...	...	...	...
I														
1. Belton, G'ham	135	56	94	95	112	134	135	139	146	156	...	...	...	...
2. Thirsk	128	22	54	96	110	120	135	141	147	160	170	188	195	...
3. Scarboro'	130	53	54	99	114	112	140	143	155	...	...	180	176	...
4. Corbridge	142	59	70	104	125	140	143	146	155	163	200	199	...	...

* Observation made at Tacolneston. † Observation made at Limerick.

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TABLE III.—Date (Day of Year) of First Flowering of Plants, 1919—*continued.*

Station.	Mean Value excluding Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.
J														
1. Broughton .	146	102	82	124	133	...	144	148	156	162	189	169	...	...
3. W. Foulden .	145	...	...	109	110	133	140	146	158	167	206	200	209	...
4. Kirkcaldy .	...	61	89	...	...	...	143	...	...	179	...	199	...	305
K														
1. Beauly. .	149	...	110	121	139	141	144	150	156	159	182	195	...	...
2. Ard's Castle .	157	107	108	126	126	...	...	171	174	178	...	178	...	...

The dates in *italics* have not been taken into consideration when calculating the means for the British Isles. The figures immediately following the station names indicate the mean values used in drawing the isophenes.

Hist. J. mean, the next nine 7 days; the last ten only 3 days, these all arriving after the April winter spell.

Additional Spring Migrants. Ring ouzel, no record; reed warbler (1 only), 130; pied flycatcher (5), 134½; red-backed shrike (4), 129.

Other Migrant Movements, etc.—Last cuckoo heard (15), 181; last swift seen (10), 225; house martin (10), 281; sand martin (3), 270; first fieldfare seen (11), 288; redwing (10), 279; first song in New Year of mistle-thrush (9), 30; blackbird (19), 47½; lark (17), 55.

The Floral Isophenal Zones.

For 1919 we are further indebted to the Meteorological Office, who have supplied isohels as well as isotherms for the first half of the year. The latter in 1919 lie much further south. The 1918 outlier of 48° F. over N.W. Wales, Cheshire and N. Notts is replaced by an inlier of 45° over Derbyshire, that isotherm largely replacing 47°. It passes from the Mull to Ipswich instead of from Sutherland to Sunderland. The inrush of warm air up the Severn-Avon Vale is again marked. *Sunshine* is associated in this upward bend by the 4·5 hours isohel. Significant are 4 hour inliers over London and Birmingham, and 3·5 hour inliers from Manchester to Leeds and from Glasgow to Edinburgh. All these must affect phenological values. A tongue in the 4·5 hour isohel east from London to the N. Foreland is also significant. A less extensive bulge S. of the Goring Gap gives relatively deficient sunshine down the Thames from Reading, the isohel forming a narrow isthmus from near Oxford to St. Albans. Thus the contrast of the east-facing valley of the Thames and the Severn Valley opening south-westwards is of no small interest. The 5 hour isohel skirts the coast from Start Point to Beachy Head.

Generally speaking, the isophenal lines show a displacement southward of about seven days compared with the previous year, indicating a retardation of about one week against 1918.

With one or two exceptions (notably the isophene of 124 in Ireland, which runs almost due north and south), the general trend of the isophenes agrees very closely with that of the previous year. An excellent and interesting

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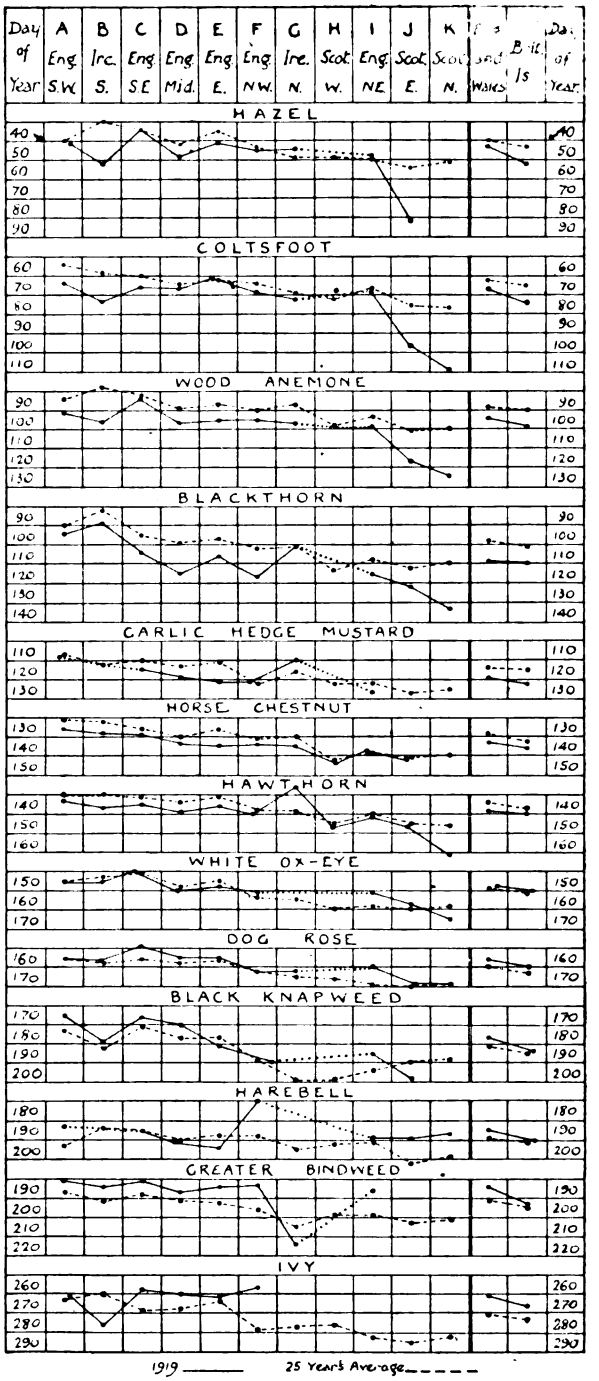

FIG. 3.—Dates of Flowering of Plants.

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TABLE IV.—Mean Dates (Day of Year) for the Flowering of Thirteen Plants in 1919, and Difference from the Average of the 25 Years 1891–1915.

Plants.	A England, S.W.			B Ireland, S.			C England, S.E.			D England, Mid.			E England, E.			F England, N.W.		
	1919.	Average 25 years.	Difference from Average.	1919.	Average 25 years.	Difference from Average.	1919.	Average 25 years.	Difference from Average.	1919.	Average 25 years.	Difference from Average.	1919.	Average 25 years.	Difference from Average.	1919.	Average 25 years.	Difference from Average.
Hazel (*Corylus avellana*)	41	40	+ 1	52	30	+ 22	34	34	0	48	42	+ 6	41	35	+ 6	45	43	+ 2
Coltsfoot (*Tussilago farfara*)	64	54	+ 10	73	58	+ 15	66	60	+ 6	67	64	+ 3	61	62	- 1	69	64	+ 5
Wood Anemone (*Anemone nemorosa*)	91	84	+ 7	96	78	+ 18	84	82	+ 2	97	89	+ 8	95	87	+ 8	95	90	+ 5
Blackthorn (*Prunus spinosa*)	94	90	+ 4	89	82	+ 7	104	95	+ 9	115	99	+ 16	106	97	+ 9	117	102	+ 15
Garlic Hedge-Mustard (*Sisymbrium alliaria*)	108	107	+ 1	...	112	...	115	110	+ 5	119	113	+ 6	121	111	+ 10	121	122	- 1
Horse-Chestnut (*Æsculus hippocastanum*)	126	121	+ 5	128	122	+ 6	129	126	+ 3	134	130	+ 4	135	126	+ 9	134	131	+ 3
Hawthorn (*Cratægus oxyacantha*)	133	130	+ 3	137	130	+ 7	135	131	+ 4	139	134	+ 5	136	131	+ 5	140	138	+ 2
White Ox-Eye (*Chrysanthemum leucanthemum*)	145	145	0	145	143	+ 2	140	141	- 1	150	148	+ 2	148	145	+ 3	151	154	- 3
Dog Rose (*Rosa canina*)	156	156	0	157	158	- 1	149	156	- 7	155	158	- 3	155	157	- 2	162	162	0
Black Knapweed (*Centaurea nigra*)	165	173	- 8	179	182	- 3	166	171	- 5	170	177	- 7	181	177	+ 4	190	189	+ 1
Harebell (*Campanula rotundifolia*)	183	193	- 10	...	184	...	185	185	0	191	190	+ 1	194	188	+ 6	170	188	- 18
Greater Bindweed (*Convolvulus sepium*)	181	187	- 6	184	191	- 7	181	188	- 7	187	191	- 4	184	192	- 8	183	196	- 13
Ivy (*Hedera helix*)	261	263	- 2	276	260	+ 16	258	269	- 11	260	268	- 8	262	264	- 2	257	279	- 22
†Mean of the 13 Plants	134	134	0	139	133	+ 6	134	134	0	141	139	+ 2	140	136	+ 4	141	143	- 2

Plants.	G Ireland, N.			H Scotland, W.			I England, N.E.			J Scotland, E.			K Scotland, N.			England & Wales.*			British Isles.		
Hazel	44	49	- 5	...	49	...	48	50	- 2	82	54	+ 28	...	51	...	43	40	+ 3	52	43	+ 9
Coltsfoot	72	69	+ 3	...	72	...	68	66	+ 2	86	75	+ 11	109	76	+ 33	66	62	+ 4	73	65	+ 8
Wood Anemone	97	87	+ 10	...	98	...	99	93	+ 6	117	101	+ 16	124	100	+ 24	94	88	+ 6	99	90	+ 9
Blackthorn	101	101	0	...	113	...	115	108	+ 7	122	112	+ 10	133	110	+ 23	109	98	+ 11	110	101	+ 9
Garlic Hedge-Mustard	110	116	- 6	...	122	...	127	122	+ 5	...	127	...	...	125	...	119	114	+ 5	122	115	+ 7
Horse-Chestnut	135	130	+ 5	144	142	+ 2	138	139	- 1	142	141	+ 1	...	140	...	133	129	+ 4	136	132	+ 4
Hawthorn	126	139	- 13	147	145	+ 2	142	140	+ 2	147	145	+ 2	161	146	+ 15	138	134	+ 4	140	137	+ 3
White Ox-Eye	...	155	...	...	160	...	151	159	- 8	157	160	- 3	165	159	+ 6	148	149	- 1	150	151	- 1
Dog Rose	162	165	- 3	...	166	...	160	169	- 9	169	170	- 1	169	169	0	156	160	- 4	160	163	- 3
Black Knapweed	...	199	...	...	199	...	185	194	- 9	198	190	+ 8	...	189	...	176	181	- 5	184	185	- 1
Harebell	...	195	...	...	192	...	189	191	- 2	189	202	- 13	187	199	- 12	185	189	- 4	190	191	- 1
Greater Bindweed	214	205	+ 9	...	199	...	186	199	- 13	...	203	...	...	201	...	184	191	- 7	193	195	- 2
Ivy	...	277	...	...	276	...	...	282	...	...	285	...	...	282	...	261	271	- 10	267	273	- 6
†Mean of the 13 Plants	144	145	- 1	...	149	...	144	147	- 3	157	151	+ 6	161	150	+ 11	139	139	0	‡144½	‡141½	+ 3

* Average of Districts A, C, D, E, F, I. + signifies that the date of flowering is late; - that it is early.
† In B, G, I, J, and K estimated or interpolated values have been utilized in deriving the mean.
‡ The mean of the 13 plants for the British Isles is given to the nearest half-day.

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TABLE V.—Mean Dates of Flowering, with their Variations from the 25 Years' Average (1891–1915), for the Thirteen Plants in those Districts where there have been sufficient Observations to warrant Comparisons being made.

Years.	A, Eng. S.W.		C, Eng. S.E.		D, Eng. Mid.		E, Eng. E.		F, Eng. N.W.		Mean Variation from Average for the 5 Districts.
	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	
		Days.		Days.		Days.		Days.		Days.	Days.
1891	144	+ 10	144	+ 9	150	+ 11	147	+ 11	150	+ 7	+ 9·6
1892†	139	+ 5	138	+ 3	144	+ 5	143	+ 7	147	+ 4	+ 4·8
1893	118	− 16	122	− 13	125	− 14	123	− 13	128	− 15	− 14·2
1894	126	− 8	130	− 5	135	− 4	127	− 9	137	− 6	− 6·4
1895	139	+ 5	138	+ 3	141	+ 2	138	+ 2	144	+ 1	+ 2·6
1896†	125	− 9	128	− 7	132	− 7	130	− 6	134	− 9	− 7·6
1897	130	− 4	132	− 3	136	− 3	132	− 4	142	− 1	− 3·0
1898	133	− 1	135	0	138	− 1	136	0	141	− 2	− 0·8
1899	136	+ 2	136	+ 1	141	+ 2	138	+ 2	145	+ 2	+ 1·8
1900	142	+ 8	141	+ 6	144	+ 5	143	+ 7	152	− 9	+ 3·4
1901	138	+ 4	139	+ 4	141	+ 2	139	+ 3	144	+ 1	+ 2·8
1902	139	+ 5	140	+ 5	145	+ 6	142	+ 6	152	+ 9	+ 6·2
1903	134	0	134	− 1	137	− 2	134	− 2	145	+ 2	− 0·6
1904†	139	+ 5	139	+ 4	142	+ 3	140	+ 4	149	+ 6	+ 4·4
1905	133	− 1	135	0	138	− 1	136	0	144	+ 1	− 0·2
1906	135	+ 1	134	− 1	138	− 1	137	+ 1	143	0	0·0
1907	142	+ 8	139	+ 4	143	+ 4	142	+ 6	149	+ 6	+ 5·6
1908†	139	+ 5	138	+ 3	142	+ 3	142	+ 6	148	+ 5	+ 4·4
1909	140	+ 6	140	+ 5	144	+ 5	142	+ 6	150	+ 7	+ 5·8
1910	136	+ 2	136	+ 1	140	+ 1	138	+ 2	145	+ 2	+ 1·6
1911	135	+ 1	133	− 2	137	− 2	134	− 2	133	− 10	− 3·0
1912†	127	− 7	128	− 7	132	− 7	130	− 6	134‡	− 7‡	− 6·8
1913	125	− 9	126	− 9	134	− 5	130	− 6	142	− 1	− 6·0
1914	126	− 8	128	− 7	133	− 6	129	− 7	135	− 8	− 7·2
1915	133	− 1	134	− 1	139	0	137	+ 1	142	− 1	− 0·4
1916†	132	− 2	132	− 3	141	+ 2	140	+ 4	142	− 1	0·0
1917	142	+ 8	141	+ 7	149	+ 10	145	+ 9	148	+ 5	+ 7·8
1918	131	− 3	131	− 3	134	− 5	134	− 2	135	− 8	− 4·2
1919	134	0	134	0	141	+ 2	140	+ 4	141	− 2	+ 0·8
Mean 1891–1915	134	...	134·5	...	139	...	136	...	143	...	[137·4]

† Leap years. ‡ Average of 12 plants (dog rose omitted).

§ *Explanation of the Dates in the Tables.*

1– 31	are in January.	182–212	are in July.
32– 59	,, February.	213–243	,, August.
60– 90	,, March.	244–273	,, September.
91–120	,, April.	274–304	,, October.
121–151	,, May.	305–334	,, November.
152–181	,, June.	335–365	,, December.

§ In Leap Years allow for one day after February 28.

comparison, for instance, is that of 124 for 1919 with 117 for 1918 and 130 for 1917. From Wellington all three run in a south-easterly direction toward Dorchester—in the latter two years the southerly bulge includes the Bill of Portland. Two well-defined northerly crests, divided by a loop skirting the Isle of Wight, precede the very definite pushing southward of the isophene by

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TABLE VI.—Date (Day of Year) of Song and Migration of Birds, and First Appearance of Insects, 1919.

Song-Thrush (*Turdus musicus*) first heard; Swallow (*Hirundo rustica*) first seen; Cuckoo (*Cuculus canorus*) first heard; Nightingale (*Daulias luscinia*) first heard; Flycatcher (*Muscicapa grisola*) first seen; Swallow (*Hirundo rustica*) last seen; Honey-Bee (*Apis mellifica*); Wasp (*Vespa vulgaris*); Small White Butterfly (*Pieris rapæ*); Orange-Tip Butterfly (*Anthocaris cardamines*); Meadow-Brown Butterfly (*Epinephile janira*) first seen.

Station.	Song.	Migration.					Insects.				
	Song-Thrush first heard.	Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Wasp.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.
A											
1. Falmouth	...	116	124	...	145	270	...	103	109	152	161
2. Duloe	3	98	108	...	...	...	68	...	94	107	143
3. Tiverton	54	109	108	...	...	...	...	...	...	...	...
4. Wellington	...	101	...	...	...	...	75	...	...	...	...
5. Street	3	104	107	128	119	273	...	66	113	113	128
6. Winscombe	13	108	119	...	140	259	...	159	111	113	161
7. Weymouth	...	113	114	...	...	...	...	80	97	138	...
8. Ansty, Dorchester	...	106	108	...	...	293	93	134	109	130	...
9. Pulham	16	103	110	148	...	295	...	203	107	107	...
10. Edmondsham	7	...	...	...	...	...	...	...	...	...	...
11. Verwood	10	100	107	104	136	...	...	110	109	113	165
12. Bridgend	3	109	125	...	...	...	110	137	119	143	161
13. Hafod, Aberystwyth	...	126	116	...	136	263	75	108	133	138	...
B											
1. Ferns	3	115	114	...	124	287	...	94	116	126	129
2. Vale of Clara	24	...	...	...	...	...	...	...	...	...	...
3. Mountmellick	13	110	110	...	140	267	19	116	123	127	152
C											
1. Bournemouth	...	108	...	...	...	...	...	...	...	...	...
1a. Lymington	...	102	108	121	...	...	...	...	...	...	...
2. Beaulieu	3	109	113	112	...	279	72	134	118	134	140
3. Marlborough	4	102	114	...	132	...	...	...	139	128	165
4. Botley	2	116	107	124	129	280	59	95	96	133	144
5. Bembridge	2	98	106	122	...	305	97	97	125	136	...
6. Petersfield	...	99	108	...	128	279	58	67	129	133	...
7. Havant	7	96	109	121	...	287	72	86	95	130	...
8. Chichester	3	108	109	...	...	293	54	95	108	...	160
9. Fleet	1	...	109	...	124	270	109	...	...	...	144
10. Farnham	14	102	115	133	...	...	...	...	...	...	...
11. Hove	1	116	123	...	140	288	103	107	126	147	161
12. Cuckfield	11	120	111	131	133	271	64	107	124	124	148
13. Lower Beeding	...	95	103	...	130	...	...	128	...	126	...
14. Cranleigh	12	99	107	...	140	...	...	...	97	136	...
15. Purley	16	123	108	128	...	...	94	129	130	137	166
16. Hellingly	1	107	108	105	134	314	*2*	*2*	*40*	108	109
17. Maidstone	16	110	110	114	...	270	108	123	126	134	...
D											
1. Oxford	...	107	111	120	...	...	...	...	...	143	...
2. Weston Turville	...	112	124	109	...	278	...	137	108	137	...
3. Ross	8	109	109	...	...	...	...	128	129	129	...
4. Dymock	19	106	113	...	144	*227*	...	111	...	130	...
5. West Malvern	7	107	106	...	122	271	107	175	150	132	144
6. Ashorne	51	112	113	...	...	282	108	131	129	...	161
7. Farnborough	26	98	116	131	130	240	108	176	108	132	166
8. Northampton	17	...	114	128	132	278	108	124	...	149	...

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TABLE VI.—Date (Day of Year) of Song and Migration of Birds, and First Appearance of Insects, 1919—*continued.*

Station.	Song.	Migration.					Insects.				
	Song-Thrush first heard.	Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Wasp.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.
9. Staunton-on-Arrow	11	96	110	...	132	274	...	94	108	123	173
10. Bromyard	22	...	...	...	...	...	...	...	...	...	...
11. Tenbury	5	106	108	123	123	276	72	125	123	128	167
12. Wolverley	...	108	...	129	133	278	...	...	124	...	...
13. Quinton	22	117	107	...	140	271	74	97	132	141	161
14. Kilbworth	5	125	125	132	...	...	...	...	129	135	149
15. Glaston	15	...	142	...	131	274	...	...	129	132	...
16. Edgmond, Newport	8	123	120	...	...	278	96	121	125	121	...
17. Hodsock	37	108	115	...	...	301	43	111	110	133	...
18. Sitwell Vale	15	118	124	...	...	...	54	137	131	...	...
19. Goole	24	124	123	...	...	272	...	...	...	...	...
20. Kirkheaton	54	129	130	...	...	257	144	...	130	...	...
21. Middlestown	52	132	121	...	...	268	101	130	110	161	...
22. Hebden Bridge	...	108	123	...	138	...	...	...	...	...	...
23. Altofts	...	...	114	...	...	...	108	...	...	...	...
24. Tadcaster	...	109	121	...	...	...	108	...	130	136	166
26. Crosshills	45	107	120	...	...	291	72	123	133	...	...
27. Menston-in-Wharfedale	...	...	129	...	...	...	...	...	...	...	...
E											
1. Watford	...	125	108	...	193	280	65	111	110	...	...
2. Berkhamstead	13	102	116	125	148	284	60	109	124	140	...
3. Bennington	52	...	111	137	163	275	...	194	...	161	...
4. Letchworth	20	100	104	113	124	291	61	55	108	129	142
5. Lexden	51	124	113	124	146	282	93	97	109	130	...
6. Cambridge	10	125	117	...	...	...	59	122	125	134	...
6a. Bungay	8	112	118	115	130	280	*20*	60	120	117	195
7. Hapton	...	110	...	...	...	...	...	...	...	131	...
8. Norwich	...	...	109	...	...	...	...	...	...	...	...
9. King's Lynn	...	127	123	...	...	...	...	...	130	137	197
10. Hevingham	...	125	114	...	...	...	...	...	...	...	...
11. Stalham	51	...	...	...	...	280	...	129	103	128	...
F											
1. Birkenhead	12	114	...	...	...	...	134	...	121	143	143
2. Scarisbrick	27	121	124	...	...	...	124	126	128	...	...
3. Southport	...	127	127	...	...	...	...	128	126	...	...
4. Leyland	...	112	125	...	...	273	...	110	110	...	...
5. Urswick, Ulverston	12	99	122	...	...	301	53	99	100	144	185
6. Ulverston	16	108	112	...	127	298	...	...	...	137	...
7. Ambleside	17	100	126	...	133	271	70	140	130	135	...
8. Ambleside	...	100	121	...	131	...	...	...	...	...	...
G											
1. Rostrevor	...	...	*70*	...	...	...	102	...	...	...	...
2. Enniskillen	...	105	114	...	132	276	54	...	...	110	...
3. Belfast	...	109	119	...	...	263	...	...	...	...	...
5. Westport	...	109	121	...	...	287	61	...	...	...	...
5a. Magherafelt	17	120	112	...	...	272	...	...	...	...	...
6. Altnafoyle	21	116	120	...	...	...	...	...	111	147	200
H											
1. Kirkmaiden	10	112	135	...	...	285	82	131	...	...	134
2. Moniaive	...	97	117	...	...	295	69	133	134	...	...
3. Milngavie	...	118	125	...	...	...	...	...	135	...	...

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TABLE VI.—Date (Day of Year) of Song and Migration of Birds, and First Appearance of Insects, 1919—*continued.*

Station.	Song.	Migration.					Insects.				
	Song-Thrush first heard.	Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Wasp.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.
I											
1. Belton, Grantham	49	102	105	...	...	...	54	...	124	136	...
2. Thirsk	1	112	112	...	...	271	...	...	131	159	...
3. Scarborough	28	103	113	...	127	...	...	...	...	...	...
4. Corbridge	53	129	130	...	...	...	...	...	...	...	...
J											
1. Broughton	...	123	124	...	130	279	62	133	131	...	...
2. Broughton	...	124	123	...	130	...	...	...	...	...	...
3. West Foulden	5	109	135	...	...	282	...	133	133	...	178
4. Kirkcaldy	25	139	...	...	...	272	114	134	130	...	...
5. Ellon	23	109	142	...	...	...	55	130	...	...	...
K											
1. Beauly	...	130	128	...	...	...	80	137	162	...	...
2. Ardross Castle, Alness	53	130	125	...	...	262	98	132	126	129	...
Mean of A (England S.W.)	14	108	113	127	135	276	84	122	110	125	153
Mean of B (Ireland S.)	13	113	112	...	132	277	...	105	120	127	141
Mean of C (England S.E.)	7	106	110	121	132	285	81	106	118	131	149
Mean of D (Midlands)	23	113	118	125	133	274	93	128	124	135	161
Mean of E (England E.)	29	117	113	123	151	281	68	110	116	134	178
Mean of F (England N.W.)	17	110	122	...	130	286	95	121	119	140	164
Mean of G (Ireland N.)	19	112	117	...	...	275	72	...	...	129	...
Mean of H (Scotland W.)	...	109	126	...	...	290	76	132	135	...	...
Mean of I (England N.E.)	33	112	115	...	...	...	...	...	128	148	...
Mean of J (Scotland E.)	18	121	131	...	130	278	77	133	131	...	...
Mean of K (Scotland N.)	...	130	127	...	...	...	89	135	144	...	...
Mean of British Isles, 1919	19 Jan. 19	114 Apr. 24	119 Apr. 29	124 May 4	135 May 15	280 Oct. 7	82 Mar. 23	121 May 1	125 May 5	134 May 14	158 June 7
25 years Mean 1891–1915	Jan. 22	Apr. 18	Apr. 24	Apr. 23	May 15	Oct. 10	Feb. 26	Apr. 12	Apr. 20	May 10	June 14
1919. Difference from 25 years Mean	−3	+6	+5	+11	0	−3	+25	+19	+15	+4	−7

The British Isles means in Table VI. are the means of the separate Districts; in Table VII., of the original records.

the South Downs, which then follows a more regular course north-eastward to disappear off the East Anglian coast. The general direction here outlined is confirmed by the 120 isophene for 1916.

The control of the isophenal line by the orographical features is very clearly indicated. With more data this isophene should furnish excellent

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TABLE VII.—SPRING

STATION.	Mean Value.†*	Wheatear (*Saxicola œnanthe*).	Chiffchaff (*Phylloscopus rufus*).	Wryneck (*Iynx torquilla*).	Willow Warbler (*Phylloscopus trochilus*).	Swallow (*Hirundo rustica*).	Sand Martin (*Cotile riparia*).	Tree Pipit (*Anthus trivialis*).	Yellow (Ray's) Wagtail (*Motacilla Rai*).	Blackcap (*Sylvia atricapilla*).	Cuckoo (*Cuculus canorus*).
A_2 Duloe	105·8	...	88	...	99	98	...	59	...	120	108
A_5 Street	112·9	...	68	...	...	104	96	...	...	...	107
A_6 Winscombe	115·1	93	96	109	108	108	...	123	117	123	119
A_9 Pulham	115·7	...	92	...	...	103	...	...	...	125	110
A_{11} Verwood	112·5	88	94	108	101	100	100	105	106	112	107
B_1 Ferns	113·5	...	85	...	94	115	...	...	...	...	114
C_1 Bournemouth	115·2	...	92	...	95	108	109	113	...	109	...
C_{1a} Lymington	115·5	...	94	108	...	102	104	...	...	...	108
C_3 Marlborough	115·6	...	108	...	110	102	...	108	...	...	114
C_4 Botley	115·9	...	95	115	114	116	...	...	...	114	107
C_7 Havant	113·3	74	94	113	98	96	96	108	...	107	109
C_{12} Cuckfield	120·6	...	107	121	120	120	...	123	134	132	111
C_{13} Lower Beeding	114·3	...	97	108	99	95	...	...	...	...	103
C_{15} Purley	116·2	...	...	...	109	123	...	...	...	...	108
D_3 Ross	118·8	...	...	116	110	109	110	108	115	...	109
D_4 Dymock	119·7	...	98	...	112	106	...	...	...	...	113
D_5 W. Malvern	118·1	...	94	...	...	107	...	...	...	...	106
D_7 Farnborough	118·5	...	102	...	98	98	...	...	*135*	...	116
D_9 Staunton	113·4	...	95	...	106	99	103	...	...	126	110
D_{11} Tenbury	112·1	92	95	107	109	106	...	108	99	108	108
D_{12} Wolverley	119·9	...	94	...	...	108	*136*	...	...	...	...
D_{13} Quinton	120·9	...	110	114	...	117	127	...	...	...	107
D_{14} Kibworth	120·6	...	108	...	...	125	97	...	...	...	125
D_{20} Kirkheaton	122·7	...	*171*	...	129	129	...	130	...	...	130
D_{22} Hebden Bridge	120·6	...	...	...	...	108	...	...	123	...	123
D_{25} Wilsden	118·8	86	...	...	103	...	...	...	...	...	...
E_4 Letchworth	114·0	100	76	109	101	100	107	107	115	96	104
E_6 Cambridge	122·3	...	...	...	...	125	126	...	...	...	117
E_9 King's Lynn	121·6	*144*	...	...	...	127	120	...	...	...	123
F_6 Ulverston	121·9	113	...	...	108	108	*130*	...	...	...	112
F_8 Ambleside	121·2	100	115	...	111	100	122	124	111	...	121
G_2 Enniskillen	120·7	94	97	...	107	105	118	...	...	...	114
G_3 Belfast	122·8	...	108	...	...	109	...	...	...	...	119
I_3 Scarborough	121·1	101	102	...	109	103	...	109	122	...	113
J_2 Broughton	122·1	93	...	...	109	124	106	...	...	...	123
J_4 Kirkcaldy	124·3	103	...	...	114	139	...	...	...	...	...
J_5 Ellon	123·1	118	...	...	...	109	122	...	74	...	142
Total records used	593	13	27	12	28	88	17	13	10	11	86
Mean, 1919	117·5	96·5	96·5	111·3	106·6	114	111·3	109·6	111·6	115·6	119
,, 6 yrs., 1914–19	117·5	99·3	100·1	105·2	107·0	112·2	112·9	113·4	116·8	112·9	117·1
,, N.H.J., 1877–96	112·3	93	94	102	103	104	106	107	109	110	110

†* The *Station* values are obtained by allowing for blanks by interpolation of the mean bird values for
The *Bird* values are the mean of all actual records, except abnormally late

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MIGRANT TABLE, 1919.

Nightingale (*Daulias luscinia*).	House Martin (*Chelidon urbica*).	Whinchat (*Pratincolarubetra*).	Redstart (*Ruticilla phœnicurus*).	Whitethroat (*Sylvia cinerea*).	Sedge Warbler (*Acrocephalus phragmitis*).	Sand Piper (*Totanus hypoleucus*).	Grass Hopper Warbler (*Locustella nævia*).	Lesser Whitethroat (*Sylvia curruca*).	Wood Warbler (*Phylloscopus sibilatrix*).	Corncrake (*Crex pratensis*).	Turtle Dove (*Turtur communis*).	Garden Warbler (*Sylvia hortensis*).	Swift (*Cypselus apus*).	Nightjar (*Mulgus europæus*).	Spotted Flycatcher (*Muscicapa grisola*).
...	99	...	...	120	...	...	...	...	121	94	...	...	110	133	...
128	...	68	...	...	...	...	...	...	...	...	96	...	126	...	119
...	122	(Rsdnt.)	...	121	...	...	117	108	...	127	138	123	123	126	140
148	...	...	...	...	...	...	...	...	...	...	126	...	*171*	...	...
104	119	...	...	120	111	...	120	112	113	130	124	128	119	134	136
...	...	...	...	...	110	...	...	...	...	110	...	...	120	...	124
...	...	...	112	...	...	116	...	127	...	...	...	...	125	...	...
121	...	...	...	...	...	...	...	...	...	...	...	...	124	...	...
...	94	...	...	112	...	...	...	...	...	...	...	...	125	...	132
124	...	...	...	...	...	...	...	...	...	...	132	...	124	...	129
121	117	...	...	...	112	...	*170*	...	112	...	136	...	125	136	...
131	119	...	...	124	131	...	...	*151*	...	...	127	...	126	143	...
...	...	...	...	...	...	...	...	...	...	...	126	...	123	...	130
128	...	...	...	...	...	...	...	...	...	...	130	...	125	...	...
...	...	...	...	...	...	...	...	137	...	...	...	...	117	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	127	...	144
...	122	...	*155*	...	...	...	...	...	...	*146*	122	*154*	132	...	122
131	125	...	...	114	...	...	...	...	...	...	130	129	124	...	130
...	109	...	119	126	...	105	125	...	127	...	127	...	124	...	132
123	113	107	113	105	119	...	123	108	110	136	131	123	125	96	123
129	...	...	...	...	...	...	...	...	...	130	...	...	125	...	133
...	126	...	...	122	119	...	...	133	138	114	132	120	128	...	140
132	...	...	...	...	...	...	...	...	...	...	...	...	130	...	...
...	*161*	130	...	...	...	...	...	...	...	131	...	...	...	...	...
...	131	...	123	131	125	124	...	...	131	...	...	...	113	...	138
...	133	...	...	...	...	103	...	...	...	...	...	...	134	140	...
113	107	134	...	124	124	124	111	113	...	133	113	116	125	135	124
...	128	...	...	126	129	...	...	125	...	...	128	...	125	...	...
...	129	...	...	...	...	...	...	...	...	...	...	...	138	143	...
...	128	127	...	126	*131*	*131*	...	...	...	123	...	...	125	...	127
...	122	127	115	129	...	113	...	...	118	129	...	130	125	129	131
...	...	...	...	127	127	...	128	...	...	109	...	...	125	...	132
...	...	...	...	135	130	...	134	...	...	120	...	...	120	...	...
...	108	...	...	...	...	111	...	...	...	122	...	...	124	...	127
...	102	134	...	130	...	107	...	...	...	128	...	...	128	...	130
...	129	...	...	...	...	...	...	...	...	131	...	...	130	...	...
...	...	...	...	...	...	...	...	...	...	129	...	...	127	...	...
25	23	7	5	18	11	9	8	8	8	27	19	7	44	10	39
124	119	118·1	116·4	122·2	121·5	112·5	122·4	120·4	121·2	123·7	126·5	124·1	125·1	131·5	135
118·3	119·1	119·9	117·2	120·7	122·3	115·6	119·1	118·3	121·3	124·5	126·8	124·9	124·7	133·5	135·3
111	111	113	112	113	115	117	118	118	119	121	123	125	125	119	128

neighbouring parts; namely, (1) of those preceding the Midlands, (2) the Midlands, and (3) those following.
ones shown in italics, without any interpolation.

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TABLE VIII.—OBSERVATIONS OF TREES AND SHRUBS TAKEN AT ST. MICHAEL'S, TENBURY, WORCESTERSHIRE, 1919, BY FREDERICK LOWE.

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.	Fruit Ripe.
Alder	*Alnus glutinosa*	Mar. 24	April 22	May 13	Sep. 24	Oct. 24	Nov. 6	Oct. 4
Apple (Wild)	*Pyrus malus*	May 14	April 20	May 11	Aug. 11	Oct. 18	Nov. 4	Oct. 3
								early main
,, (Garden)	*Pyrus malus sativus*	May 10	April 28	May 11	Aug. 15	Oct. 20	Nov. 12	Aug. 5–Sep. 6
Ash	*Fraxinus excelsior*	April 23	May 10	May 19	Sep. 13	Oct. 16	Oct. 26	Sep. 24
,, (Mountain)	*Pyrus aucuparia*	May 16	April 17	May 7	Sep. 3	Oct. 14	Oct. 31	Aug. 10
Acacia	*Robinia pseud-acacia*	June 8	May 21	May 26	Sep. 10	Oct. 25	Nov. 12	Sep. 24
Almond	*Amygdalus communis*	Mar. 24	April 21	May 9	Sep. 11	Oct. 25	Nov. 11	Oct. 10
Berberis	*Berberis Darwinii*	April 17	April 29	May 11	...	(Casting	May 29)	July 30
Berberis	*Berberis aquifolium*	April 17	May 5	May 13	...	(Casting	May 22)	Aug. 2
Barberry	*Berberis vulgaris*	May 19	April 18	May 6	Sep. 7	Oct. 14	Nov. 19	Sep. 20
Blackthorn	*Prunus spinosa*	April 22	April 27	May 8	Sep. 8	Oct. 18	Nov. 15	Sep. 3
Birch	*Betula alba*	May 5	April 19	May 5	Aug. 13	Oct. 15	Nov. 10	Aug. 24
Beech	*Fagus sylvatica*	May 7	April 25	May 6	Aug. 10	Oct. 15	Nov. 12	Sep. 7
Bullace	*Prunus insititia*	April 30	April 24	May 5	Sep. 12	Oct. 20	Nov. 5	Aug. 31
Box	*Buxus sempervirens*	Feb. 28	April 19	May 16	...	(Casting	May 24)	Aug. 16
Currant (Black)	*Ribes nigrum*	April 30	April 9	April 30	July 13	Oct. 5	Nov. 20	June 26
,, (Red)	*Ribes rubrum*	April 20	April 15	May 2	July 13	Sep. 14	Oct. 14	June 24
Chestnut (Horse)	*Æsculus Hippocastanum*	May 12	April 16	May 4	Sep. 6	Oct. 7	Oct. 29	Sep. 16
,, (Spanish)	*Castanea vesca*	June 16	May 8	May 19	Aug. 17	Oct. 17	Nov. 12	Oct. 14
Cherry (Wild)	*Prunus avium*	April 23	April 18	May 7	Sep. 8	Oct. 19	Nov. 2	July 6
,, (Bird)	*Prunus padus*	May 14	April 26	May 10	Aug. 19	Oct. 24	Nov. 2	July 17
,, (Garden)	*Cerasus vulgaris*	May 3	April 27	May 14	Aug. 31	Oct. 19	Oct. 30	June 18
Cypress (Common)	*Cupressus sempervirens*	April 20	May 6	May 24	...	...	...	Sep. 30
Cedar	*Cedrus Libani*	Sep. 25	May 4	May 24	...	(Casting	Apr. 7)	Oct. 20
Dogwood	*Cornus sanguinea*	June 6	May 4	May 14	July 14	Oct. 4	Oct. 28	Sep. 14
Deutzia	*Deutzia crenata*	June 6	April 15	May 4	Sep. 7	Oct. 31	Nov. 19	July 25
Elm (Common)	*Ulmus campestris*	Mar. 4	May 13	May 23	Sep. 24	Nov. 2	Nov. 24	May 14
,, (Cornish)	*Ulmus stricta*	Mar. 13	May 2	May 13	Sep. 25	Nov. 4	Nov. 17	May 5
,, (Cork)	*Ulmus suberosa*	Mar. 30	May 13	May 21	Sep. 8	Oct. 20	Nov. 12	May 12
,, (Wych)	*Ulmus montana*	Apr. 1	May 10	May 16	Aug. 9	Oct. 7	Oct. 24	May 13
Elder	*Sambucus nigra*	May 27	April 6	April 28	Aug. 5	Oct. 3	Nov. 11	Aug. 29
Fir (Spruce)	*Abies excelsa*	May 1	May 9	May 20	...	(Casting	Aug. 23)	Sep. 14
,, (Scots)	*Pinus sylvestris*	May 9	May 16	May 29	...	(Casting	Aug. 21)	Sep. 28

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TABLE VIII.—OBSERVATIONS OF TREES AND SHRUBS TAKEN AT ST MICHAEL'S, TENBURY, WORCESTERSHIRE, 1919—*continued.*

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.	Fruit Ripe.
Gooseberry	*Ribes grossularia*	April 19	April 4	April 18	July 14	Sep. 26	Nov. 1	July 10
Gorse	*Ulex europæus*	Jan. 4	April 28	May 15	...	...	...	June 8
,, (Dwarf)	*Ulex nanus*	July 28	May 8	May 26	...	...	...	Nov. 2
Hazel	*Corylus Avellana*	Feb. 25	April 20	May 12	July 14	Oct. 10	Nov. 9	Sep. 4
Hawthorn	*Cratægus oxyacantha*	May 19	April 11	April 29	Aug. 9	Oct. 8	Nov. 1	Aug. 29
Holly	*Ilex aquifolium*	May 17	May 5	May 26	...	(Casting	May 20)	Sep. 28
Honeysuckle	*Lonicera caprifolium*	May 11	Jan. 1	April 16	Aug. 9	Oct. 4	Nov. 6	July 20
,, (Wild)	*Lonicera periclymenum*	June 2	Jan. 1	April 18	Aug. 17	Oct. 6	Nov. 9	Aug. 9
Ivy	*Hedera helix*	Sep. 11	May 4	May 16	...	(Casting	Feb. 7)	Mar. 13
Japonica	*Pyrus Japonica*	Mar. 15	Feb. 28	April 18	Sep. 7	Oct. 31	Nov. 26	Sep. 30
Jasmine (Yellow)	*Jasminum nudiflorum*	Sep. 21	April 11	May 7	Aug. 4	Sep. 30	Nov. 7	...
,, (White)	*Jasminum officinale*	June 20	May 7	May 26	Oct. 1	Oct. 22	Dec. 20	Sep. 24
Kerria	*Kerria Japonica*	April 20	April 18	May 10	Aug. 13	Oct. 11	Nov. 11	July 26
Laburnum	*Cytisus laburnum*	May 17	April 25	May 12	July 26	Oct. 22	Nov. 17	Aug. 30
Laurustinus	*Viburnum tinus*	Dec. 1, 1918	April 25	May 25	...	(Casting	May 21)	Aug. 27
Laurel (Portugal)	*Cerasus lusitanica*	June 12	May 4	May 26	Aug. 27	(Casting	June 25)	Sep. 29
,, (Spurge)	*Daphne laureola*	Jan. 7	Mar. 28	May 12	Aug. 13	(Casting	June 15)	June 10
,, (Variegated)	*Aucuba cerasus*	May 14	April 25	May 26	...	(Casting	May 25)	...
,, (Common)	*Cerasus laurocerasus*	April 19	May 6	May 26	...	(Casting	April 10)	Sep. 26
Larch	*Pinus Larix*	April 11	April 13	April 28	Aug. 13	Oct. 27	Nov. 18	Aug. 24
Lilac	*Cytisus laburnum*	May 15	April 15	May 3	Aug. 29	Oct. 9	Oct. 27	Sep. 28
Lime	*Tilia europæa*	July 12	May 8	May 15	Aug. 10	Oct. 8	Oct. 24	Sep. 2
Lavender	*Lavendula vera*	July 20	April 20	May 10	....	(Casting	Sep. 3)	Sep. 11
Maple (Field)	*Acer campestre*	May 14	May 10	May 16	Sep. 10	Oct. 6	Oct. 28	Sep. 29
,, (Norway)	*Acer Platanoides*	April 20	May 6	May 12	Aug. 31	Oct. 3	Oct. 24	Sep. 20
Medlar	*Mespilus Germanica*	May 28	April 19	May 4	Sep. 18	Oct. 20	Nov. 16	Oct. 26
Mezereon	*Daphne mezereum*	Jan. 1	Mar. 13	April 18	Aug. 13	Oct. 2	Nov. 14	June 27
Mistletoe	*Viscum album*	Feb. 24	May 6	June 8	...	(Casting	April 10)	Oct. 22
Oak	*Quercus robur*	May 6	May 7	May 14	Sep. 10	Oct. 24	Nov. 24	Oct. 1
Oak	*Quercus sessiliflora*	May 10	May 10	May 16	Sep. 3	Oct. 17	Nov. 10	Sep. 28
Poplar (White)	*Populus alba*	April 13	May 10	May 15	Sep. 4	Oct. 14	Nov. 5	May 12
,, (Grey)	*Populus canescens*	April 19	May 15	May 23	Sep. 7	Oct. 22	Nov. 6	May 9
,, (Black)	*Populus nigra*	April 17	May 8	May 15	Aug. 15	Oct. 3	Oct. 24	May 5

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TABLE VIII.—Observations of Trees and Shrubs taken at St. Michael's, Tenbury, Worcestershire, 1919—*continued*.

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.	Fruit Ripe.
Poplar (Lombardy)	*Populus fastigiata*	April 15	May 3	May 13	Sep. 8	Oct. 20	Nov. 2	April 29
,, (Aspen)	*Populus tremula*	Mar. 28	May 10	May 16	Sep. 3	Oct. 16	Nov. 5	May 8
Privet	*Ligustrum vulgare*	June 11	April 15	May 6	Aug. 17	(Casting	Nov. 9)	Sep. 14
Pear (Common)	*Pyrus communis*	May 6	April 29	May 10	Sep. 8	Oct. 10	Oct. 24	Sep. 18
Plum (Common)	*Prunus domestica*	May 4	May 2	May 13	Aug. 21	Sep. 30	Oct. 26	Aug. 22
,, (Pershore)	*Prunus Pershorum*	May 3	April 19	May 11	Sep. 3	Oct. 17	Oct. 26	Aug. 23
Quince	*Cydonia vulgaris*	May 14	April 13	May 1	Sep. 16	Oct. 20	Nov. 23	Oct. 23
Ribes	*Ribes floridum*	April 15	April 8	April 30	July 24	Oct. 10	Nov. 28	Aug. 8
Rosemary	*Rosmarinus officinalis*	April 12	April 28	May 21	...	(Casting	Sep. 1)	July 29
Raspberry	*Rubus idæus*	May 25	April 11	April 30	July 14	Oct. 12	Nov. 15	July 4
Rose (Guelder)	*Viburnum opulus*	May 26	April 23	May 13	Aug. 25	Oct. 10	Oct. 30	Aug. 19
,, (Field)	*Rosa arvensis*	June 15	April 6	April 24	July 14	Oct. 6	Nov. 8	Sep. 20
,, (Dog)	*Rosa canina*	May 31	April 11	April 25	July 14	Oct. 8	Nov. 10	Sep. 4
Service (Wild)	*Pyrus torminalis*	May 28	May 12	May 21	Sep. 14	Oct. 12	Oct. 28	Sep. 20
Snowberry	*Symphoricarpus racemosus*	May 31	April 6	April 24	Aug. 16	Oct. 19	Nov. 10	Sep. 4
Syringa	*Philadelphus coronarius*	May 30	April 16	May 4	Aug. 16	Sep. 25	Oct. 20	Sep. 12
Spindle	*Euonymus europæus*	May 23	April 19	May 9	Aug. 29	Oct. 18	Nov. 9	Oct. 6
Sycamore	*Acer pseudo-platanus*	April 28	April 19	May 3	Aug. 29	Oct. 9	Oct. 27	Sep. 18
Traveller's Joy	*Clematis vitalba*	July 25	May 4	May 22	Sep. 9	Oct. 27	Nov. 12	Sep. 9
Willow (Goat)	*Salix caprea*	April 12	May 1	May 13	Aug. 17	Oct. 20	Nov. 14	May 19
,, (Common)	*Salix fragilis and viminalis*	May 4	April 24	May 6	Aug. 8	Oct. 15	Nov. 10	June 2
,, (White)	*Salix alba*	May 9	May 2	May 10	Aug. 15	Oct. 22	Nov. 16	June 2
Walnut	*Juglans Regia*	May 19	May 7	May 20	Aug. 16	Oct. 15	Oct. 27	Oct. 4
Yew	*Taxus baccata*	Mar. 2	May 7	May 21	...	(Casting	May 28)	Aug. 15

Notes:—First general fall of the leaf, Aug. 27. First heavy fall of the leaf, Oct. 14. Trees generally leafless, Nov. 20.

Owing to the mild and wet weather during the latter part of 1918, trees and vegetation generally were in an advanced stage of growth during Jan., and gave promise of an early spring, but the prolonged wintry weather, which began at the end of Jan. and lasted till the beginning of May, considerably checked all growth during that period, and the flowering and leafing of trees, etc., was therefore later than usual.

As a result of the very dry, windy, and warm weather of June, July, Aug., many trees began to cast their leaves quite early, in fact, some Beeches, Wych Elms, and Hazels were practically leafless by Aug. 23.

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groundwork for the critical application of Hopkins' Bioclimatic Law,[1] so far as the altitude factor is concerned.

In similar manner the close approximation in general direction of the 131 isophene of 1919 to that of 124 for the previous year can be traced, and the controlling features identified. And generally, the effect of increased altitude is evidenced by the pushing southward or south-westward of the latitude direction of an isophenal line.

The pronounced oblique tendency of the isophene crossing Central Ireland from N.W. to S.E. is well marked on the present year's map, and less so for the two previous years. With an increase in the number of stations in Ireland it will be of great interest to see whether the generally regular direction of the Irish isophenes is maintained.

The reappearance of the late isophenes over Norfolk is interesting.

The two relatively "early" isophenes of 117 for 1918 running, one south-west from Cambridge, the other north from Bristol in the general direction of the Severn Valley, are this year replaced by the *one* irregular isophene of 124.

DISCUSSION.

Mr. J. H. Pease said he was glad to see new stations along the north-east coast. A point for investigation was that by common repute everything there was earlier than inland, the probable cause being not so much the mitigating circumstances of a coast line as that, at any rate in north Yorkshire, there was often a very narrow belt of sunshine when north-east winds caused massed clouds inland. The isohels shown possibly confirmed this.

The President (Mr. R. H. Hooker) said he thought the thrush should be excluded from the list of records, as he sang on any nice, fine, warm day that occurred. With regard to the isophenes he very much doubted whether the time had come to do a proper map of them. He thought the observations were not sufficiently numerous nor well chosen to form the basis of a good map. It was clear from the drawing of the lines that in some parts of the country they depended on two or three observations only. Despite the distinct instructions on the form there would probably be a pronounced tendency on the part of observers to look for the earliest flower, whereas the conscientious observer would take his first primrose, say, from the main portion of a bank rather than from a plant in a specially favoured corner. Looking at the isophene of 117 it would be noticed that a corner of Suffolk exposed to the east winds appeared to be earlier than the warm south coast of Dorset. He was very suspicious of that, and of the wobbles round Portsmouth, as they were probably due to the idiosyncrasies of observers, one having perhaps a position facing south, and

[1] *The Bioclimatic Law.*—Attention should be called to the interesting phenological researches of Dr. Andrew Hopkins, of the U.S.A. Department of Agriculture (*Washington, D.C., Monthly Weath. Rev.*, 1918, Supplement 9; *Sci. Mon. New York, N.Y.*, June 1919). The establishment of his Bioclimatic Law marks an important step forward in the practical value of phenological observation and data.

The law proposes a progression or regression, according to season, of plant life at the unit rate of four days for each degree in latitude, or five degrees of longitude [in North America], or four hundred feet of altitude.

The latitudinal rate of variation is confirmed for the British Isles by our own phenological maps. The determination of the rates of longitude and altitude is a somewhat more complex problem. Our stations are few and the orographical features extremely varied and, when considering the longitudinal movement of plant life, distinctly preponderating. With the promised large increase in observers for 1920 and future years we hope that the necessary data will be forthcoming whereby to confirm or otherwise for the British Isles the bioclimatic law in all its phases.

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another facing north. Referring to the isohels, the President said that sunshine generally coincided with cold during the winter, and he believed that accumulated temperature rather than sunshine was the more important factor in the appearance of flowers. He hoped Mr. Clark would be able to get isopleths of accumulated temperatures, especially for the plants appearing in the first few months, the appearance of which could hardly be associated with sunshine.

Mr. CARLE SALTER suggested that it might be better to experiment with plotting departures from normal. This would, besides having other advantages, eliminate the idiosyncrasies of observers.

Mr. J. EDMUND CLARK in reply said he fully agreed with the President as to the desirability of having accumulated temperatures. As to the isophenes, they were encouraged by finding, in spite of the few observers, the decided correspondence from year to year, as in the curious curve round the Isle of Wight, which, though unexpected, yet reappeared.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

May 19, 1920.

Ordinary Meeting.

Mr. R. H. HOOKER, M.A., President, in the Chair.

Lieut. JOHN GORBELL GOODYEAR, R.A.F., Summerhill, Hythe, Kent; and Prof. BENNETT MELVILL JONES, M.A., Engineering Laboratory, Cambridge, were balloted for and elected Fellows of the Society.

The following communications were read:

1. "AGRICULTURAL CLIMATOLOGY OF AUSTRALIA." By Dr. GRIFFITH TAYLOR (p. 331).

2. "REPORT ON THE PHENOLOGICAL OBSERVATIONS IN THE BRITISH ISLANDS FROM DECEMBER 1918 TO NOVEMBER 1919." By J. EDMUND CLARK, B.Sc., F.R.Met.Soc., and HENRY B. ADAMES, F.R.Met.Soc. (p. 407).

June 16, 1920.

Ordinary Meeting.

Sir NAPIER SHAW, F.R.S., Vice-President, in the Chair.

WILLIS RAY GREGG, 1757 Columbia Road, Washington, D.C., U.S.A.;
GEORGE ROBERT HAY, Eastcote, 3 Blenheim Park Road, South Croydon;
FREDERIC WILLIAM MACAULAY, M.Inst.C.E., Springfield House, Ludlow;
HENRY CLARK MCKINLEY, Thanestead Cottage, Loudwater, Bucks.;
PERCY RICHARD SHARMAN, 54 Shrewsbury Road, New Southgate, N.11:
Captain BERTRAM J. SHERRY, 3032 N Street, N.W., Washington, D.C., U.S.A.; and
CONWAY VAUGHAN-STARR, 69 London Road, Gloucester,
were balloted for and elected Fellows of the Society.

The following communications were read:

1. "THE ETHER DIFFERENTIAL RADIOMETER." By W. H. DINES, F.R.S., F.R.Met.Soc. (p. 399).

2. "THE COMPOSITION, IONISATION AND VISCOSITY OF THE ATMOSPHERE AT GREAT HEIGHTS." By Prof. S. CHAPMAN, F.R.S., D.Sc., F.R.Met.Soc., and E. A. MILNE, B.A. (p. 357).

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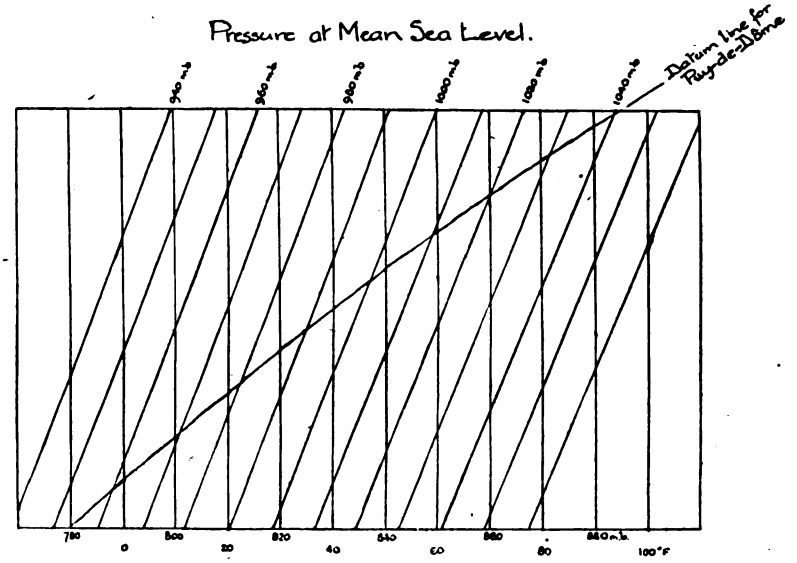
CORRESPONDENCE AND NOTES.

A Nomogram for obtaining the Mean Temperature of an Air Column from the Pressure at the Top and Bottom.

Meteorological observations taken on the Puy-de-Dôme and at Clermont-Ferrand, a much lower station, are received daily in the Meteorological Office, Air Ministry. The stations differ little in latitude and longitude, and the Clermont pressure is reduced to sea-level, while that from the Puy-de-Dôme is not. A nomogram, illustrated in the figure, has been constructed to provide a ready means of deducing from these two pressures the mean temperature of a column of free air from the Puy-de-Dôme to sea-level, roughly 1·5 k., with a view to utilising this knowledge in forecasting. The nomogram is foolscap



Pressure at Station-Level (upper row). Harmonic Mean Temperature (lower row).

FIG. 1.

size and bears the instructions:—"Take the Puy-de-Dôme pressure on the pressure scale at the bottom of the diagram. Move vertically to the oblique straight line representing the sea-level pressure (Clermont reduced barometer reading) according to the scale at the top of the diagram. Then move horizontally to the right or left as far as the red [1] curve, and finally vertically downwards to the temperature scale at the bottom of the diagram. The reading (to the nearest whole degree Fahrenheit) will give the mean temperature (harmonic mean of temperatures measured from absolute zero) of a column of free air of the height of the Puy-de-Dôme." Besides the lines shown in the figure, the original has additional oblique lines for every 2-mb. pressure, and the whole is drawn on squared paper which provides intermediate vertical lines and facilitates use.

If p_0 denote the sea-level pressure, p_1 the Puy-de-Dôme pressure, h the

[1] The single curve crossing the figure is in red on the original.

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height in k. of the Puy-de-Dôme Observatory (1·467 k.),[1] and T the (harmonic) mean absolute temperature of a column of free air from Puy-de-Dôme to sea-level, then $T = 14{\cdot}837\, h/\log(p_0/p_1)$ (*Computer's Handbook*, M.O. 223, Sec. 2, Meteorological Office, London). It is required to evaluate T for varying values of p_0 and p_1. Denoting the ratio p_1/p_0 by r, then

$$p_1 = p_0 r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$T = -14{\cdot}837\, h/\log r \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The nomogram first evaluates r from (1), and then T from (2). Taking p_1 as abscissa and r as ordinate, the graph of (1), for a given value of p_0, is a straight line, and assigning in turn different values to p_0, we get a family of straight lines. These are the oblique lines in the figure. They all converge to the origin of co-ordinates which is a considerable distance outside the boundary of the nomogram. Taking T as abscissa and r as ordinate (using the same scale for r as before), the graph of (2) is the single curved line in the figure. On the nomogram the scales for p_1 and T, the latter in degrees Fahrenheit, are shown at the bottom, and the value of p_0 appropriate to each oblique line is indicated at the top. The scale for r is not used, and so is omitted.

In using the nomogram, when we move vertically to the appropriate oblique line we are finding the point whose ordinate is the value of r, and when we complete the operation we are finding the abscissa T (required) corresponding to this ordinate. Two points are noteworthy. The oblique lines intercept on any particular horizontal line distances which are equal, and this renders the construction easy. Also the nomogram is very compact, any pair of values p_0, p_1, each possible alone, which necessitates passing outside the boundary, being impossible, since they would yield a mean temperature outside the range of possible values.

The nomogram is here applied to the particular case of the Puy-de-Dôme, but the principle is clearly capable of more general use. By using a series of "red" (curved) lines it can be applied for stations at different heights; it can also be applied to reduce barometer readings to sea-level, or to obtain heights from readings of pressure and temperature. The single curve in the figure is only one of a family obtained by varying h. Nomographical methods are often very useful in evaluating a function of more than one independent variable and could find extensive applications in meteorology. M. A. GIBLETT.

Cloud Phenomenon seen at Nottingham, 14th June 1920.

At 17.30 h. a dark black cloud mass was seen blowing up from S.S.W.; the surface wind was E by S and fracto-stratus in small quantities was seen coming from this direction; the zenith and eastern sky were practically clear.

When the edge of the dark cloud passed over it was seen to be a straight line from E.S.E. to W.N.W. and to be in violent commotion. In a few seconds it was apparent that the front of the cloud mass was one vast roller cloud from horizon to horizon, while a dense sheet of stratus stretched behind it about on a level with the top of the roller.

In appearance it was exactly similar to the line-squall sketched by Mr. G. A. Clarke, on page 188 of the *Meteorological Glossary*, but the similarity to a line-squall stopped here. There was a lull in the wind, which remained E by S except for a veer to SW for a few seconds just after the back of the roller cloud passed the zenith. Temperature dropped 3° F. The lower surface of the clouds came from E. by S. the whole time, right till the end of the storm which followed.

[1] Height taken from *Bulletin International du Bureau Central Météorologique*, May 1920. Now ascertained to be incorrect. Correct height is 1450 m.

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An unusual sight was presented by the edge, as though the individual clouds were bearing from E. by S.; the whole mass was moving rapidly N.N.E.

As the back of the roller passed the zenith it at once became apparent that the whole of the back was falling at a great pace, curling under the cloud and moving forward. This motion could have been no illusion, as it was not only plainly visible in the zenith, but an almost sectional view was obtained by watching the cloud on either side towards the horizon. Great masses of vapour could be seen falling in wreaths and coils, turning under the cloud with a smooth and rounded edge. As the cloud moved farther away towards the N.N.E. horizon, it looked like a tremendous curtain hung from a sheet of cloud; in the N.W. and N. it was divided into massive well-defined columns as if a dark strato-cumulus sky had suddenly tipped vertically down, stopping just short of the ground. The lower edge of the cloud could be seen as a straight but jagged edge just above the horizon. Towards the N.E. and E. the sky could be seen through the "curtain"; the back was still falling at a terrific pace, but through gaps in it the front part could now be seen rising equally rapidly. (This rising motion was carefully referred to the ground to eliminate the possibility of an apparent motion which could be given to a stationary cloud by the proximity of falling clouds.)

From the observed motions I have drawn the following conclusions.

The roller cloud was revolving anti-clockwise.

The cloud was a hollow cylinder for these reasons. Though of diameter of a mile or more, the sky could be seen through gaps in its vertical section which presented a mottled, almost festooned appearance. Clouds at the back were seen falling; those at the front, or at least in front of these, were seen rising, but none could be seen vertically stationary, as vapour at the centre would be.

Considering all these conditions I am strongly inclined to believe that the roller cloud was a horizontal cylindrical vortex revolving anti-clockwise. Its translatory movement was normal to its axis, and for the following reason tangential to the isobars round a low pressure area.

The movement of the cloud mass was to N.N.E. and the wind was E by S; here we have the usual incurvature of the wind in front of a depression. The roller cloud was from E.S.E. to W.N.W. Buys Ballot's law gives the direction of low pressure and an approximate indication of the isobaric distribution.

Since writing this report the following notes on the atmospheric conditions at the time have been prepared for me by the courtesy of the Director of the Meteorological Office. I reproduce them word for word.

Weather Reports for 14.6.20, with Reference to Cloud Phenomenon at Nottingham.

"There is no clear evidence in the available reports of any line-squall moving from S.S.W. to N.N.E. on the evening of 14th June 1920. It seems, also, unlikely that such a squall would move radially outwards from a low pressure area to a high pressure area, crossing the isobars at right angles.

"The phenomenon described by Mr. Granger appears to be one of the effects of a rain-band, trending from Yarmouth *via* Liverpool to Malin Head. This rain-band, however, did not move, but was remarkably persistent. It is shown clearly on the 7, 13 and 18 h. charts and vestigially on the 21 h. chart. Throughout the day it does not appear to have swayed more than 25 miles from its mean position. There are no pronounced temperature differences on the two sides of the belt, and no well-defined convergence of the wind. In fact the temperature distribution and the wind direction appeared totally indifferent to its existence.

"The belt, however, which lay very accurately along an isobar, did separate

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an anticyclonic region with fair to fine weather on the N.E. from a cyclonic region with variable cloud and some showers on the S.W. It was associated with thunderstorms or heavy rain in the morning (7-13 h.) at Didsbury and Benson ; in the afternoon (13-18 h.) at Holyhead, Liverpool, Nottingham, and Didsbury ; and at night at Nottingham, Didsbury, Cranwell, and Buxton.

"The axis of Mr. Granger's horizontal vortex lay parallel to this rainbelt, and the phenomenon appears to have been associated with some slight motion of it.

"It is worth noting that no upper air observations indicated any wind from South. Up to the highest level the winds were from E to ESE. The N.N.E.-ward movement of the cloud was therefore not due to an upper air current. J. LOGIE."

It is hard to supply any theory as to the formation of the vortex, if such it was, but I would like to lay stress on the following points.

1. There was no SW current up to 18,500 feet ; the cloud certainly did not reach this height, hence it seems certain that the rain-band was not moving bodily from S.W. at all, but was extending itself rapidly N.E., *i.e.* the thermal conditions necessary for cloud formation were being propagated in a N.E. direction regardless of the direction of air currents.

2. The cylindrical vortex marked the positions where the thermal conditions were changing so suddenly as to produce dense masses of vapour out of clear air in an apparently stable condition. There was no cirrus or other cloud connected with the rain-band in front of the vortex.

R. FRANCIS GRANGER.

NOTTINGHAM, *July* 28, 1920.

The Meteorology of British Somaliland.

Somaliland, the "Horn of Africa," has hitherto been little known meteorologically. Hann devotes only a few lines to it, based on one year's observations at Zeila, but data for twelve years at Berbera are now available,[1] besides a few figures at Sheikh in the interior, and they seem of sufficient interest to warrant a short discussion.

Somaliland is a monsoon country, coming under the influence of the pressure changes over Southern Asia. Table I., which is based on a summary prepared in the Meteorological Office, shows that NE winds blow from October to May to the exclusion of most other directions, while July and August are occupied by the SW monsoon. This alternation of wind direction co-operates with the altitude of the sun in determining the annual variation of climate. Temperature is very high, the mean for the year at Berbera being 85° F. The cool season, with mean temperatures below 80° F., extends from November to March. Towards the end of May, with the setting in of hot SW winds from the interior, the temperature rises rapidly, the mean exceeding 95° F. from June to August, while the midday temperatures regularly exceed 100° F. in the shade and have reached 116° or 117° F. Similar high temperatures are recorded farther west at Zeila ; in fact the figures seem to rise and fall together at the two places. The monsoon changes are the most unhealthy seasons to Europeans, but the hot period is very trying, especially to the nervous system. This season, known as the "Kharif," is characterised by terrific gales of sand-laden winds, especially in the forenoon. The atmosphere is very dry, the relative humidity averaging below 50 per cent with little diurnal variation. In the high interior the humidity averages about 70 per cent and temperatures are much lower ; at Sheikh (4500 feet above M.S.L.) they range from about 60° F. in January to 75° F. in June and July. These months accordingly

[1] 1906 and 1907 have since been received. The rainfall figures have been added in Table II.

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TABLE I.—Monthly Averages and Extremes at Berbera, 10° 22′ N., 45° 2′ E. Height above M.S.L. 31 ft.

Month.	Mean Pressure at M.S.L.	Mean Temperature (24 hrs.)	Mean Daily Extremes.		Mean Monthly Extremes.		Absolute Extremes.		Relative Humidity.*	Cloudiness.*	Precipitation.			Wind.*									
														Gale days.	Mean Force.	Percentage of Observations from—							
			Max.	Min.	Max.	Min.	Max.	Min.			Amount	Days	Max. fall in 24 hrs.			N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm
	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	%	ins.		ins.		0–12									
January . .	1015·1	76·1	85·0	69·2	88	64	94	55	72	27	0·12	1	0·46	2	2·5	0	59	14	4	0	0	0	1	22
February . .	1015·5	76·1	84·7	69·6	87	65	92	54	73	27	0·31	1	1·50	1	2·5	0	66	12	3	0	1	0	0	18
March . .	1012·7	78·1	86·4	72·4	89	68	95	52	74	26	0·73	1	5·20	1	2·0	0	59	2	1	0	5	2	0	31
April . .	1011·2	81·7	90·1	76·9	96	73	108	67	74	21	0·49	2	1·50	1	1·8	0	60	0	0	0	3	0	0	37
May . .	1008·7	87·3	96·1	80·8	106	77	112	72	68	14	0·39	1	1·50	1	2·0	5	51	1	0	0	8	0	0	35
June . .	1004·7	95·7	105·9	86·6	111	81	117	78	50	10	0·00	0·1	0·02	14	5·1	8	25	0	1	0	38	0	2	26
July . . .	1004·4	97·4	106·7	88·3	110	81	116	72	43	24	0·11	0·7	0·41	23	6·8	9	3	0	0	0	62	4	2	20
August . .	1005·0	96·6	105·7	87·0	110	82	116	63	44	19	0·05	0·5	0·30	17	6·1	11	8	0	0	0	52	1	2	26
September .	1007·4	91·2	101·3	82·6	108	76	114	64	53	13	0·03	0·3	0·16	4	2·6	8	24	0	10	0	22	0	0	36
October . .	1012·4	83·3	92·7	77·1	97	71	107	64	65	9	0·05	0·4	0·60	0	1·8	1	48	2	16	2	2	0	1	28
November .	1014·4	79·1	88·9	71·3	92	65	98	63	67	12	0·03	0·3	0·23	0·2	1·9	1	49	16	13	1	2	0	0	18
December .	1015·9	77·1	87·0	68·8	90	64	94	60	71	21	0·07	0·6	0·40	1	2·0	0	55	10	13	1	0	0	0	21
Year . .	1010·6	85·0	94·2	77·5	112†	62‡	117	52	63	19	2·38	9	5·20	65	3·1	4	42	5	5	0	16	1	1	26
No. of Years .	10	12							8		12			12	9	3 to 4							

* Based on observations at 7 h., 13 h., and 19 h. Winds for 1918 and 1919, 8 h., 13 h., 20 h.

† The mean of the highest temperature each year.

‡ The mean of the lowest temperature each year.

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show decreases with height of 3°·5 F. and nearly 5° F. per thousand feet respectively. The data for Sheikh are shown in Table IV.

The variation of rainfall is especially interesting. At Berbera and Zeila, on the coast, practically all of the small rainfall occurs in the early months of the year, especially from February to May, which four months at Berbera

TABLE II.—Monthly Rainfall at Berbera, 1906–1919.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
1906	0·09	0·87	4·80	0·10	0·02	...	...	...	..	...	0·60	0·54	7·02
1907	0·03	..	...	0·43	...	...	...	0·10	0·27	...	0·11	...	0·94
1908	0·63	0·10	...	...	...	...	0·32	0·05	...	...	...	0·16	1·26
1909	0·15	...	...	1·33	1·25	...	...	...	...	...	...	0·16	2·89
1910	0·02	...	5·78	...	0·20	...	0·06	0·30	...	...	...	...	6·36
1911	0·45	...	0·65	0·20	...	...	...	...	...	...	0·05	...	1·35
1912	...	0·16	...	1·84	...	...	...	...	...	...	...	0·50	2·50
1913	0·03	1·04	0·70	...	1·50	...	...	...	...	...	...	...	3·27
1914	...	0·54	...	...	1·35	...	...	0·02	0·07	0·65	...	...	2·63
1915	...	...	...	0·31	0·03	...	...	...	0·16	...	0·08	...	0·58
1916	0·07	1·81	0·05	...	...	...	0·61	0·24	0·09	...	...	0·02	2·89
1917	...	0·01	...	0·20	0·07	0·02	0·23	0·02	...	...	...	...	0·55
1918	0·09	...	...	1·44	0·12	...	0·05	...	...	...	0·23	...	1·93
1919	...	0·01	1·62	0·51	0·17	...	...	...	...	...	...	...	2·31

"..." signifies that no rain fell.

average 1·92 inches out of an annual total of 2·38 inches. December to April have an average cloudiness of two to three tenths, but during the rest of the year the sky is practically cloudless, the relatively high figures for July and August probably being due to dust haze. The rain falls usually in short showers, but occasional "cloudbursts" are experienced. 4·80 inches fell on March 22, 1905, out of an annual total of 7·71 inches, and again, in March

TABLE III.—Diurnal Variation of Wind at Berbera.
Percentage of winds from different directions.

Direction.	January to May.			July, August.			October to December.		
	7 h.*	13 h.	20 h.†	7 h.*	13 h.	20 h.†	7 h.*	13 h.	20 h.†
N	0	0	0	0	29	1	0	1	0
NE	24	98	57	0	4	13	4	99	50
E	2	0	12	0	0	0	4	0	23
SE	5	0	0	0	0	0	25	0	18
S	0	0	0	0	0	0	2	0	0
SW	9	0	2	98	45	29	4	0	0
W	1	1	0	0	7	0	0	0	0
NW	0	1	0	0	5	0	0	0	0
Calm	59	0	29	2	10	57	61	0	9

* 7 h. for 2 years, 8 h. for 2 years. † 20 h. for 2 years, 21 h. for 2 years.

1910, 5·20 inches out of an annual total of 6·36 inches fell on the 18th. If this fall had not occurred, the average rainfall for March would have been only 0·30 inch instead of 0·73—which shows the futility of relying too strictly on rainfall normals in such a climate.

In the interior the conditions are reversed. At Sheikh the annual average is much higher—21 inches; but though only a few miles from Berbera, the

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greater part of this rain falls between April and November, of which all except the first two months are dry on the coast. The fall is much more reliable than at Berbera, and the coast towns depend on the hills for their water-supply, which is brought to Berbera in pipes from a spring, but to Zeila by the more archaic method of water-skins. The source of this summer rainfall, brought by the SW winds, can only be the Atlantic Ocean—it is, in fact, the same wind which gives birth to the Nile flood, the height of which is correlated with the wind and pressure at St. Helena. On the other hand, the winter fall is derived from the small amount of moisture which the NE wind can pick up in its journey across the Red Sea. The extreme variability of this fall is shown by Table II.

Lastly, a word about the diurnal variation of winds at Berbera. These are shown in Table III., and illustrate the effect of land and sea breezes on the dominant monsoon. First, from October to May we have the NE monsoon.

TABLE IV.—Monthly Averages at Sheikh, 9° 50′ N., 45° 16′ E.
Height, 4500 feet.

Month.	Temperature.					Relative Humidity.*	Rainfall.	
	Mean ¼(8+13+2×21 h.).	Mean Daily Extremes.		Absolute Extremes.				
		Max.	Min.	Max.	Min.		Amount.	Days.
	° F.	° F.	° F.	° F.	° F.	%	ins.	
January .	60·1	68·0	53·5	78	40	79	0·22	1½
February .	64·7	74·9	55·5	81	43	73	0·01	0
March .	...	...	...	86	49	...	0·09	0
April . .	70·8	79·6	62·1	89	51	77	3·43	12
May . .	73·5	84·7	64·2	95	53	75	3·53	13
June . .	75·1	87·5	64·2	91	60	66	0·28	2
July . .	75·1	87·7	63·6	92	61	71	1·95	2
August .	73·5	85·5	63·0	90	60	71	1·96	6
September .	74·7	86·0	64·3	90	60	72	2·18	20
October .	66·5†	72·7	61·1	88	53	...	3·72	8
November .	61·8†	72·3	52·1	83	41	77	3·03	7½
December .	62·1	65·5	55·7	77	42	86	0·75	4
Year . .	(69·0)	(78·5)	(59·8)	95	40	...	21·15	76
No. of Years	1			2		1	2–3	1–2

* Observations at 8 h., 13 h., and 21 h. † Interpolated.

In the early morning this clashes with the land breeze, resulting in 60 per cent of calms. From October to December, with a slightly more easterly direction of the monsoon, there is also a resultant SE wind on 25 per cent of the days, and at this hour the NE wind is almost in abeyance during these months. At 13 h. the sea-breeze reinforces the monsoon, calms are unknown, and NE is practically the sole wind direction. 20 h. is intermediate between the other two hours.

July and August, the months of the SW monsoon, show very different conditions. Here the land-breeze reinforces the monsoon, which reaches gale force every morning for days at a stretch, July actually averaging 23 days when winds of gale force are reported. But at midday, under the intense heat, the sea-breeze becomes strong enough to neutralise or overcome the monsoon on half the days, giving 10 per cent of calms and 33 per cent of N or NE winds, while in the evenings 57 per cent of calms are recorded. The diurnal variation of wind force (0–12) is as follows:

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	7 h.	18 h.	20 h.		7 h.	18 h.	20 h.
January .	*1·1*	**4·3**	2·2	July .	**8·1**	6·5	*5·7*
April . .	*0·7*	**3·5**	1·3	October .	1·3	**3·2**	*1·0*

During twelve years two fogs were recorded at Berbera, both in January 1916. In the hills mist is frequent in the rainy months and may persist all day.

C. E. P. BROOKS.

Evidence of Meteorological Conditions in the Distant Past.

This summer a considerable area of "submerged forest" has been visible in the west coast of Wales south of the Dovey estuary, near the little village of Borth. Usually a fine sandy shore stretches out for some distance, but it has long been known that beneath the sand there existed the remains of a submerged forest, as from time to time a few tree stumps standing in the underlying peat have been exposed. For some months in the summer of 1920 the sand has been removed from a much greater area than usual. Three or four patches of forest have been visible: one, 200 yds. by 12, shows some stumps and occasionally peat; some 200 yds. south there is another patch 600 yds. by 30; 100 yds. south of this strip a few more stumps appeared through the sand, and about half a mile farther south again there were a few more.

Little could be made of most of what was visible, but the central portion of the second strip gave an exceedingly interesting exposure. Here were to be seen not only the peat and the stumps *in situ*, but tree trunks 10 or 12 feet long, most of which had been broken off, but some of which had been uprooted. Nearly all of them were still more or less embedded in the peat, and even when not partly covered by peat were at least sunk into it. There was no possibility that they had been overturned since submergence, and it is thus most probable that they were thrown down while still at a higher level. In 21 cases it could easily be determined which was the upper and which the lower end, so that in these cases the direction of fall could be fixed, while in 5 cases this was doubtful. The 21 cases are summarised thus:

Fall to	N	NE	E	SE	S	SW	W	NW
so that the wind was from	S	SW	W	NW	N	NE	E	SE
Number of trees	1	4	8	3	3	0	1	1

The fact that the trees lie in so many directions makes it improbable that they were blown over by one gale. The evidence, such as it is, rather indicates that the prevalent strong winds were from some westerly quarter as now. More than half of the cases indicate either a West or a South-west wind. It may be accident, but it was noticed that all the uprooted trees had been uprooted by a Westerly wind, while all the five trees the sense of whose direction of fall was doubtful were lying east and west.

The date of the forest is not quite certain, but in other forests in similar situations round the coasts of Britain implements of Neolithic culture have been found, so that tentatively it may be taken that these forests were of this date. It seems likely that wind systems at that time were approximately as they are now.

Further observations were made, the significance of which is not perhaps very clear. It was noticed that the upper parts of many of the stumps had been subject to considerable abrasion. There was a good deal of fluting and many *sharp* edges were produced. The agent was not the sea. It was almost certainly *dry* blown sand, and from an examination of most of the cases it seemed probable that the sand came from some westerly direction. The evidence is not so conclusive as that given by the fallen trunks, but, such as it is, it tends to confirm the conclusion already reached.

It is suggested that it might be possible to obtain evidence of a similar

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kind from other localities which would help to solve problems connected with the wind systems in past ages. J. FAIRGRIEVE.

Geophysical Meetings of the Royal Astronomical Society.

The series of meetings for the discussion of geophysical subjects, which have been held in the rooms of the Royal Astronomical Society, Burlington House, for several years past, will be resumed for the coming winter session on November 5. All Fellows of the Royal Meteorological Society are invited. As at present arranged the meetings will be held on the following Fridays at 5 p.m.:

Nov. 5, 1920	Geodesy.	March 4, 1921	Seismology.
Dec. 3, ,,	Terrestrial Magnetism.	May 6, ,,	Meteorology.
Feb. 4, 1921	To be arranged.	June 17, ,,	Geodesy.

Fuller particulars will appear in *Nature* or can be obtained from the Assistant Secretary, Royal Astronomical Society, Burlington House, Piccadilly, W.1.

OBITUARY.

Colonel A. BIBBY.

On May 10, at his home at Selborne, Hants, occurred the death of Colonel Alfred Bibby, late of Harthill, Allerton. He was the third son of the late John Bibby, the head of the firm of Messrs. John Bibby, Sons and Co., of Liverpool. Colonel Bibby had a successful army career many years ago, and was wounded in the Egyptian campaign, receiving the rank of Brevet Lieut.-Colonel for his services. Two of his sons gave their lives in the late war, which contributed to the ill-health from which Col. Bibby suffered and probably hastened his death.

He was elected a Fellow of this Society on January 16, 1907.

Mr. W. N. BLAIR, M.Inst.C.E.

We regret to announce the death of Mr. William Nisbet Blair, which occurred very suddenly at his residence at West Hill, Highgate, on July 15. Mr. Blair was born at Morpeth, Northumberland, on June 24, 1858, and early chose as his profession that of Civil Engineer. After some years' work in Manchester and Nottingham he obtained his first chief appointment in December 1885 as Borough Surveyor of Bootle, Lancs. From there he was appointed Chief Surveyor to the Vestry of St. Pancras in January 1892, continuing his duties as Chief Engineer under the Borough Council until his death.

Mr. Blair was a Freeman of the City of London; a Member of the Institution of Civil Engineers; a Member of the Institution of Municipal and County Engineers, of which body he was President in 1909-10; a Fellow and former Examiner of the Royal Sanitary Institute; and a Member of the Liverpool Engineering Society. He was also connected with University College, London, for several years as Lecturer and Examiner in Civil Engineering.

Mr. Blair was elected a Fellow of this Society on December 20, 1894.

Air Commodore R. M. GROVES, C.B., D.S.O., A.F.C.

With much regret we have to announce the death of Air Commodore Robert Marsland Groves, D.S.O., which occurred as the result of a flying accident at Heliopolis, Egypt, on May 27.

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Air Commodore Groves, who recently completed his 40th year, had had a very distinguished career in the Navy and the Air Force. At the outbreak of war he was one of the leading wireless officers at the Admiralty, but after a short time transferred to the Air Service. He commanded airships and subsequently held several important positions under the Air Board, becoming Deputy Chief of the Air Staff and more recently Acting Chief of the Air Force in the Middle East.

Air Commodore Groves was elected a Fellow of this Society on January 17, 1917.

Mr. T. W. Rundell.

We have to announce the sudden death from heart failure of Mr. Towson William Rundell, which took place at his residence at Lostwithiel, Cornwall, on June 17. Mr. Rundell retired from business life some years back, and subsequently lived in a quiet manner in Cornwall, where he hoped to regain his lost health. He was much respected by his neighbours and friends, and his death is deeply regretted.

Mr. Rundell was a Life Fellow of this Society, having been elected on March 15, 1899.

General M. A. Rykatcheff, Honorary Member.

At the end of 1919 a brief statement in *Terrestrial Magnetism* referred to the death of General M. A. Rykatcheff, and although no further announcement has up to the present been made, it is assumed, in view of General Rykatcheff's advanced age, that the reference is unfortunately correct. The following particulars refer briefly to the events of his career in connection with his scientific work. Michail Alexandrowitsch Rykatcheff was born in Nikolajewskoje, Russia, on December 24, 1840 (old style). He entered the Russian Navy in 1855; studied at the Marine Academy, 1862–1864, and at Greenwich, 1865–1866; became an officer of the Russian Navy in 1859 and held the rank of General-Lieutenant. In 1867 he entered the Central Physical Observatory in Petrograd, and in 1896 became Director of the Russian Meteorological Service, from which position he retired in 1913. He was a member of the Russian Geographical Society and of the Petrograd Academy of Sciences. He was appointed member of the International Meteorological Committee in 1896, and later became President of the International Commission on Terrestrial Magnetism.

He was the author of a large number of papers on meteorology and terrestrial magnetism, and also of a History of the Central Physical Observatory for the 50 years 1849–1899. Under his direction the comprehensive *Climatological Atlas of the Climate of Russia* was prepared and published in 1900.

He was elected an Honorary Member of this Society on March 21, 1900, and made several contributions to the *Quarterly Journal.*

REVIEWS.

Variation in Solar Radiation and the Weather. By H. Helm Clayton. Introductory Note by C. G. Abbot. Washington, D.C., Smithsonian Miscellaneous Collections, Vol. 71, No. 3, 1920. Pp. vi + 53, pls. 5.

The present paper is the most promising attempt yet made to find some fundamental cause of the puzzling irregular variations in the state of the

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atmosphere that we call the weather. The author goes outside the atmosphere to the variations in the intensity of solar radiation, which modern equipment enables us to determine with surprising accuracy. He works mainly by the method of correlation; the main results are obtained by correlating the observed solar radiation with the temperature, 0, 1, 2, 3, up to 40 days later. The chief data are from Buenos Aires, and their character may be judged from the following list of correlation coefficients for January and August.

Days' Interval	0	1	2	3	4	5	6	7	8	9	10
January .	−·21	−·24	·36	·40	·52	·22	·28	·16	−·11	−·49	−·24
August .	·12	·11	−·11	−·20	−·16	−·03	·16	·14	·15	·12	·07

Perhaps the most peculiar feature of this table is that the coefficients in the two months have nearly always opposite signs for the same time-interval. In the summer month of January the negative correlation for a zero interval is presumably owing to the fact that a large radiation was preceded by a period of low radiation, whose effect is not yet worn off; the excess of radiation leads to a rise in temperature, so that a very large part of the abnormality of temperature a few days later is due to the heating, and this is shown by the large positive correlation for 4 days' interval. The large negative correlation for 9 days' interval is more difficult to account for. It may be due to some sort of oscillation set up by the heating, the maximum occurring after 4 days and the minimum after 9 days; but this is not very likely, for there is no reason to believe that the atmosphere has any periods of free vibration longer than a few hours. The explanation favoured by Clayton is that as a rule about 5 days after the maximum radiation there is a minimum radiation, and that the minimum of the temperature is caused by this. Accordingly he seeks for such a periodicity in the records of radiation and temperature, and finds that the periods shown by each are very similar. The variation with time is not simple, for the period is a function of the extent of the variation, being about 6·5 days for small amplitudes and 10·5 to 11 days for large amplitudes; but even for this an explanation is suggested. The period is presumably a submultiple of the time it takes the intensely radiating region to revolve round the sun; the sun rotates fastest near the equator, so that the short period would correspond to activity there, and the longer period to activity near the poles. It is known already that solar radiation is greatest when activity is in high latitudes, so that the results agree well with our knowledge of solar phenomena.

The fact that the correlations in winter have nearly always the opposite sign to those for the same interval in summer is to be accounted for by the movements of air caused by heating in the opposite hemisphere. Air currents tend to blow towards the heated region, and if this happens to be on the other side of the equator these currents are necessarily cold and must partly or wholly neutralise the direct heating effect. That the connection is subject to much irregularity, as one would expect, is to be seen from the small values of the correlations found.

It may be asked how we know that the variations in the observed radiation and the temperature are not both due to some variation in the opacity in the air itself; for an increase in opacity would cause a fall in the apparent luminosity of the sun, which could not be readily disentangled from a true variation in the radiation, and would also cause a temporary fall and a subsequent excess of temperature. Clayton has, however, forestalled this objection by comparing his temperature observations not only with observations of radiation in Chile and Buenos Aires, but at Mount Wilson as well, and similar results are obtained. This could hardly be due to changes in opacity, for they could not often extend for such a distance. HAROLD JEFFREYS.

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Australian Meteorology; a text-book including sections on aviation and climatology. By GRIFFITH TAYLOR, D.Sc. Oxford (Clarendon Press), 1920. 8°. Pp. xi + 312. 12s. 6d.

The continual growth of interest among Australians in the meteorology of their island continent, especially since they have been brought into close contact with aviation, has made a text-book of meteorology from the Australian viewpoint desirable, and the author has filled this want very comprehensively. British or American text-books will not serve, for two reasons: firstly, because of the reversal of Buys Ballot's law in the southern hemisphere, which makes Australian weather charts so strange in our eyes; and secondly, because Australia as a whole lies nearer to the equator than do the British Isles.

As the author points out, the homologue of a large part of Australia is the Sahara region, dominated by a belt of sub-tropical highs. Highs traverse Australia very regularly from west to east at the rate of about five hundred miles a day, with intervals of about a week between the crests of the waves. The troughs between the high pressure areas are occupied by trough-like extensions of depressions passing either in the Southern Ocean or in the north of the continent; the former correspond to the Atlantic depressions crossing our islands, the latter are tropical phenomena.

This regularity in what we may call the external meteorology of Australia is complicated, however, by local effects, which in the small area of the British Isles have little importance. The two areas of strong convection (called *domes* by the author) in the north-west and north of Australia must be watched, from their tendency to give rise to well-marked troughs of low pressure extending across the continent, associated with two of the marked phenomena of Australian meteorology, hot waves from the north followed by cold "Southerly bursters." The theory of domes appears to be new in meteorology. There is also in extreme form the "seasonal character" which weather sometimes develops, when, for instance, for week after week, with low pressure, cyclonic circulation and all complete, it *will* not rain.

In Australia, on the edge of aridity, rain is of vital importance, and several chapters of the book, together with a useful "solar-control model" in the front cover, are devoted to rain, its seasonal distribution, its variability, and aids in forecasting it. The possibility of seasonal or long-period predictions is also discussed in an unusually optimistic way. It is interesting to note in this connection that attempts are now being made to calculate the past rainfall of Australia from the measurements of tree rings according to the method so successful in America. The section on aviation is rather disappointing, but there are at present little data for the writing of such a chapter, and once begun, it will certainly grow. Attention must also be called to two minor slips which need correction in any further edition. On p. 25 we are told that one megadyne equals one thousand dynes, the proper figure being of course one million, while the paragraph on p. 98 referring to the centrifugal force acting on a particle of moving air is rendered quite unintelligible owing to the writing of "west" for "east."

The volume is splendidly illustrated, of especial interest being a large number of typical Australian weather charts, which the author, owing to his close association with official meteorology in the Commonwealth, has been able to select from an abundant supply of material. C. E. P. B.

British Antarctic Expedition 1910–1913. Meteorology. By G. C. SIMPSON, D.Sc., F.R.S. Vol. I., Discussion. Pp. xi + 326, pls. 5. Vol. II., Weather maps and pressure curves. Pp. 138, pls. 23. Calcutta, 1919. 4°.

In reading this book one is struck by the great advantage it is when the work is done and the account of it given by one and the same person, especially

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when that person is as competent in both respects as Dr. Simpson has proved to be. The sad ending to the expedition must be more or less present to the minds of those who read the book, but the success of the meteorological work and the light it has thrown on many puzzling antarctic problems is apparent.

Dr. Simpson made very careful preparation for his work before going out: he designed new instruments and methods, and adapted old ones to meet the special conditions caused by the extreme cold and blizzards; and he is to be congratulated upon having kept his recording instruments running almost without a break while he was in charge of them—a difficult feat, judging by past experience; he is also to be congratulated upon the results obtained from his observations with registering balloons.

Volume I. contains a discussion of the results of this and of former expeditions. It is divided into ten chapters, Chapter IX. being on the height of the barrier and of the polar plateau, and Chapter X. on atmospheric electricity. Volume II. contains charts and curves, and Volume III., which is not yet published, is to contain statistical tables. In his preface Dr. Simpson states that he has no love for statistics, but that he has shrunk from no statistical work, however laborious, when it is required to elucidate some physical problem, and in Volume I. several such problems are discussed.

The introduction, Chapter I., gives a general description of the Ross Sea and its neighbourhood, and a summary of the various sources of information for the district. A map is provided, together with a map on tracing-paper of Western Europe on the same scale to cover it. This gives the reader in a convenient form a just idea of the distances.

Chapter II. is on temperature and its variations. It has been well established that the temperature on the barrier is, except in the summer, much lower than that in McMurdo Sound. The author explains this by pointing out that the ice over the sea is of no great thickness, that it is comparatively not a bad conductor of heat, and consequently that the heat from the water below can pass up freely, whereas on the barrier the surface is dry and formed of loose snow, which is a very bad conductor of heat. No doubt the explanation is valid for stations that are not too near the edge of the barrier, but in the reviewer's opinion it does not suffice to explain the difference, say, between Cape Evans and Corner Camp.

The low temperatures at Framheim and on the part of the barrier traversed in the journeys to the south bring the antarctic temperatures more into accordance with the values for similar latitudes in the north, and it seems as though the winter temperatures of McMurdo Sound were unduly high for its latitude. Dr. Simpson also finds two curious results in the daily variation of temperature in the dark months, for which he confesses he can offer no explanation. They are (*a*) a rise of temperature from 9 a.m. to 7 p.m. over the remainder of the day, and (*b*) a rise of temperature at 4 a.m. over that at 2 or 6 p.m. He considers he has proved the genuineness of these anomalies by splitting the observations in different ways into seven groups and finding six plus signs in one case and five in the other; but, after all, five or even six heads out of seven tosses with a coin do not suffice to prove that the coin is not genuine. The chances against it are only 7 to 121. There is an interesting discussion on temperature and wind; it is shown that the North wind is warm and the South wind cold, although the latter effect is masked by the fact that in winter any wind raises the temperature. In the preface to the *National Antarctic Expedition 1901–1904, Meteorology*, Part I., Sir Napier Shaw puts this suggestion forward, and it is confirmed by Dr. Simpson. It has come of late to be recognised that the mixing of the vertical strata of the atmosphere by wind must carry heat downwards, and estimates of the amount of heat crossing a given level have been made by G. I. Taylor and others. The mixing of the

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atmosphere must tend to make an adiabatic lapse rate, or, to put it in other words, a uniform potential temperature, just as mixing water in a bath makes a uniform temperature. Since as a rule the potential temperature of the air increases with height, mixing must carry heat downwards, but there is a certain instability about the process. If the lapse rate is small or there is an inversion, the stable condition of the air with reference to vertical motion checks the mixing, but as soon as the process has proceeded far enough to remove the inversion it can proceed more readily. This instability is probably the cause of the rapid changes both of temperature and wind velocity in the antarctic winter.

Chapter III. is on wind, but the blizzards have already been discussed under the heading wind and temperature in Chapter II. In a very interesting section curves are given showing the frequency of winds of various strengths at different stations. In places such as England, or Kerguelen in the Southern Ocean, where the weather is largely cyclonic, the greatest frequency occurs with winds of about 4 to 5 on the Beaufort scale; in places where the weather is mostly anticyclonic calms and light airs are the most frequent. This latter case is in general the rule in the antarctic, but at Cape Evans, although the maximum frequency of 22 per cent occurs with winds under 4 miles an hour, there is a secondary maximum of 8 per cent occurring at 27 miles per hour. At Framheim the frequency of calms is 42 per cent, and the curve slopes steadily downwards to the greatest velocities. Dr. Simpson's conclusion is that the weather of the Ross Sea is anticyclonic, notably so at Cape Adare, but that at Cape Evans a disturbing factor is introduced by the blizzards which he thinks are not cyclonic winds.

There are many other interesting points in this chapter.

Chapter V. is on pressure. The mean monthly values are given for Cape Adare, Cape Evans, and Framheim. The pressure at Framheim and at Cape Adare is lower than at Cape Evans, both winter and summer, but the difference is most marked in the winter. This pressure distribution implies a SE wind over the south-western section of the Ross Sea, light in summer, fairly strong in the winter. The author finds the twelve-hour period of the daily barometric variation quite apparent at Cape Evans. He devotes a considerable part of the chapter to barometric surges, and shows that these surges of high or low pressure occur more or less simultaneously over the whole Antarctic. The reason put forward is a general strengthening or weakening of the prevailing Westerly winds which blow in the upper levels of the atmosphere over all sections of the Southern Ocean.

Chapter VI. is on pressure, winds, and weather, and is perhaps the most controversial in the book. There is not space to discuss the question in a short review, but the criticism the reviewer would make is that unless a pressure difference between two places is balanced by the corresponding gradient wind, including the terms that depend on the curvature, it must be equalised in the time that sound takes to travel from one place to the other. Thus pressure waves, as defined by Dr. Simpson, moving with a velocity of the order of 30 miles an hour seem to him quite out of the question.

Chapter VIII. is on upper air observations made by means of balloons. When the difficulty of obtaining these observations in the conditions prevalent in the Antarctic are considered, one sees how greatly Dr. Simpson is to be congratulated on the skill and patience by means of which he obtained his results. His plan of recovering the instruments, worked out in England, failed, for a simple but unforeseen reason, but he was able to modify it, and out of 21 ascents to obtain 12 satisfactory records. His greatest height reached was 6·7 k. His results are remarkable, inasmuch as they continue the similarity in the lapse rate that has been found in all parts of the world in which observations have been made.

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The conditions are so different in the tropics, in temperate latitudes, and in the arctic regions, that one would naturally expect to find quite different lapse rates, but instead of that an average of about 6° C. per k. from the surface to the top of the troposphere seems to hold everywhere. The mean curve for the antarctic summer, if displaced bodily 17° C. to the right, would serve almost as the mean curve to the same height for England, and the winter curve, starting at a temperature of – 35° C., is just like the curves for Canada or Siberia in winter, nearly all of which show inversions in the lower strata. It is a pity the stratosphere was not reached, but the wonder is that observations beyond the first one or two kilometres should have been obtained.

Chapter IX. is on the height of the barrier and the south polar plateau. The height of the southern portion of the barrier is a point on which discussion arose in connection with the previous expedition. The question rests on the differences between barometer readings at Cape Evans and simultaneous readings taken by the sledge parties when on the barrier ice. These differences give a height of 170 ft. to the southern part of the barrier, but the reviewer doubts whether the evidence is conclusive. It would seem that there must be some small rise of level towards the south, otherwise what force can push the ice northwards and supply the icebergs which break off from the northern face? The question of the existence of an antarctic anticyclone is involved in the discussion, because isobaric charts cannot be drawn unless the height above mean sea-level of the observing stations is known.

Chapter X. is on atmospheric electricity. The potential gradient varied from 100 volts per metre with light winds, to over 300 with gales, the difference being due apparently to the snow drift. The observations give abnormal times for the maximum and minimum values of the daily variation. At Cape Evans, and the result agrees with those given by other antarctic stations, the maximum occurs in the forenoon, and the minimum in the afternoon, whereas in all other reliable observations out of the Antarctic, minima occur about 4 a.m. and maxima about 8 p.m. There is also a discrepancy about the annual variation. At Cape Evans the maximum potential is distinctly shown in the summer. In the northern hemisphere it is shown in the winter. Dr. Simpson's comments on this are very suggestive.

The whole book is extremely interesting and should be read by every one who wishes to obtain a comprehensive knowledge of meteorology. Parts of it are certainly open to criticism and discussion, but meteorology is as yet far from being an exact science and it is only by discussion that progress can be made.

W. H. Dines.

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